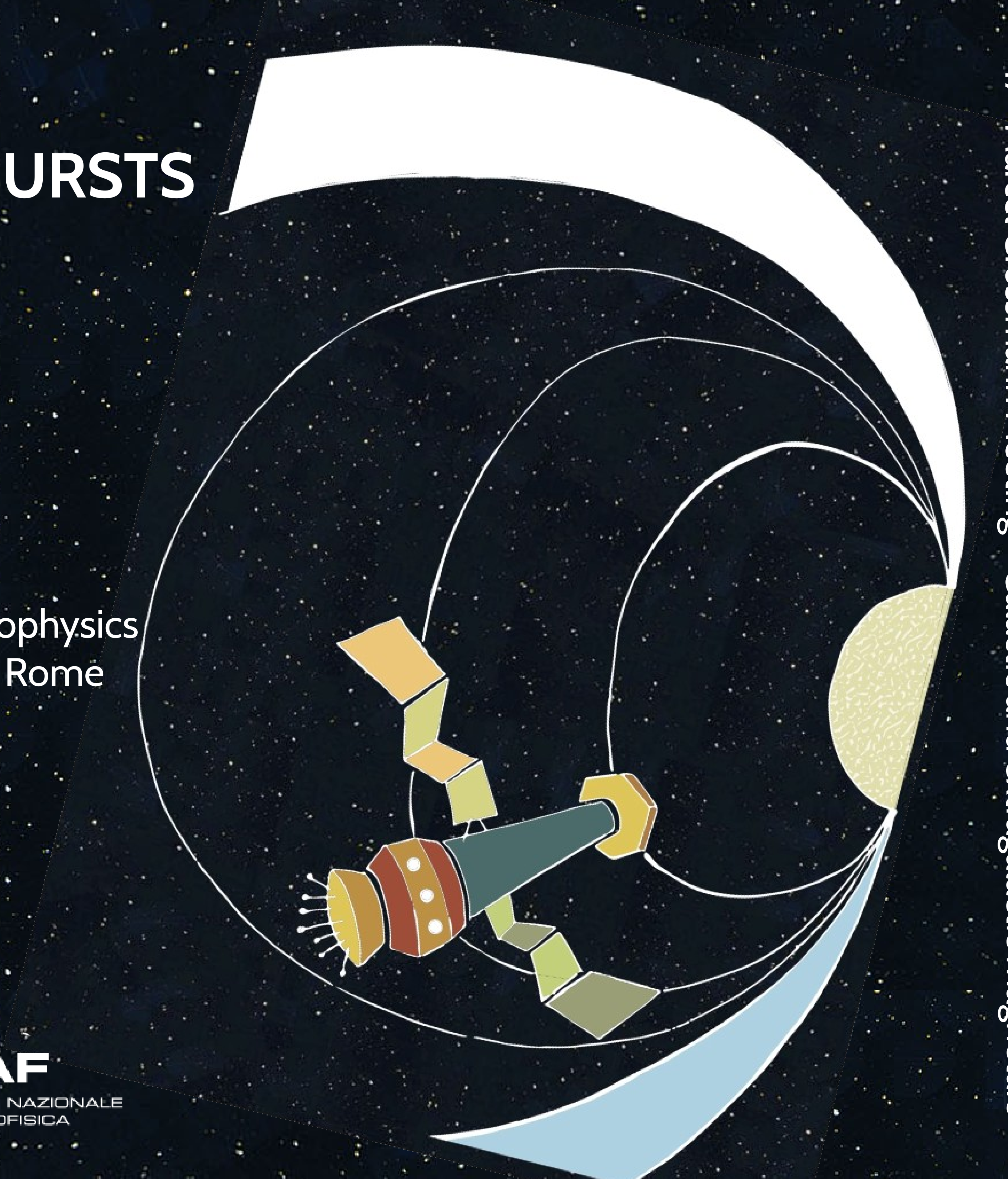
Image credit: ElenaBor

MAGNETAR OUTBURSTS AND BEYOND

Alice Borghese

Italian National Institute of Astrophysics
Astronomical Observatory of Rome



17th Marcel Grossmann Meeting - Galactic and extragalactic magnetars

For Women in Science
unesco FONDATION L'ORÉAL

INAF
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Magnetars: observational properties

~30 confirmed magnetars

$L_X \sim 10^{31}$ - 10^{36} erg s^{-1}
generally larger than the rotational energy loss rate

Dipolar magnetic fields
$B_{dip} \sim 10^{13} – 10^{15}$ G

Rotating with $P \sim 1 – 12$ s

Broadband spectra
0.5 – 100 keV
soft thermal + hard non-thermal spectral components

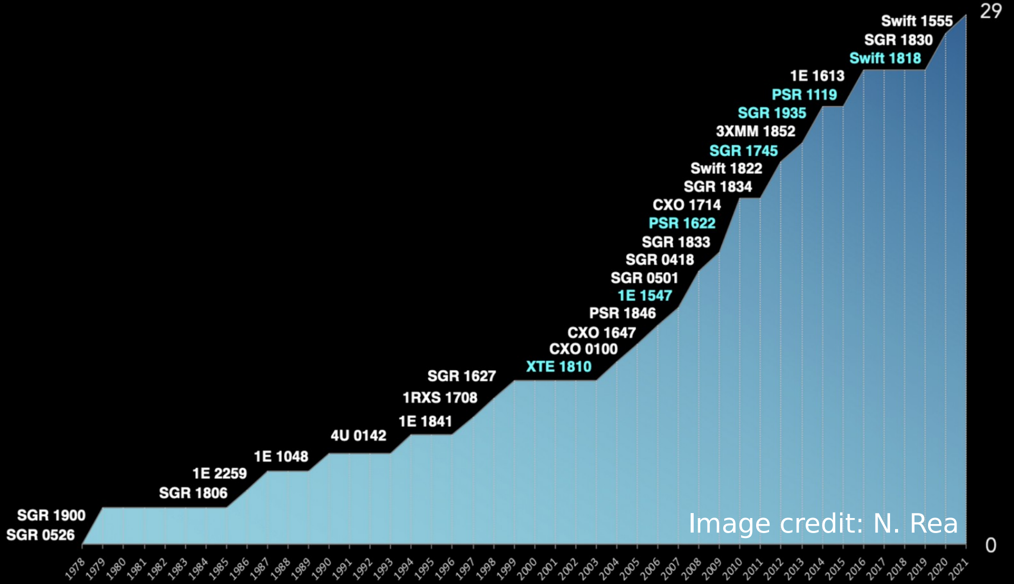


Image credit: N. Rea

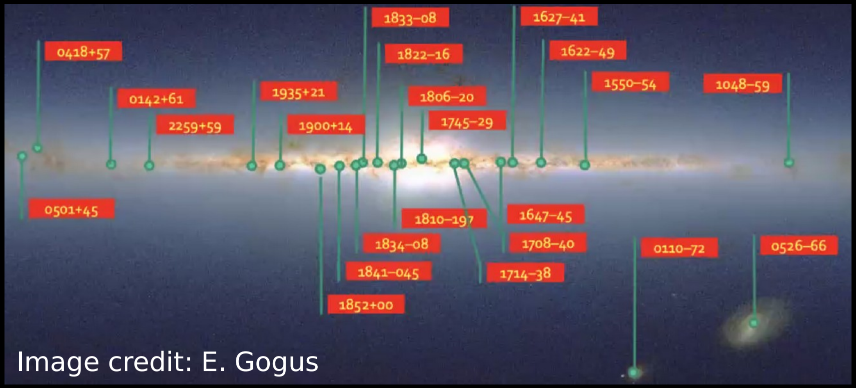
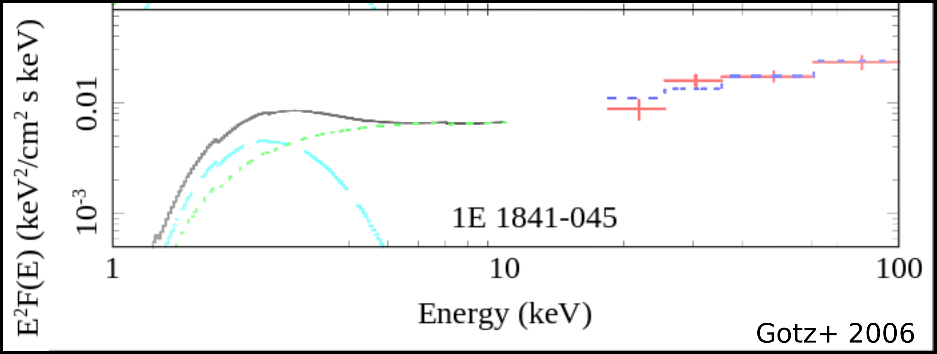


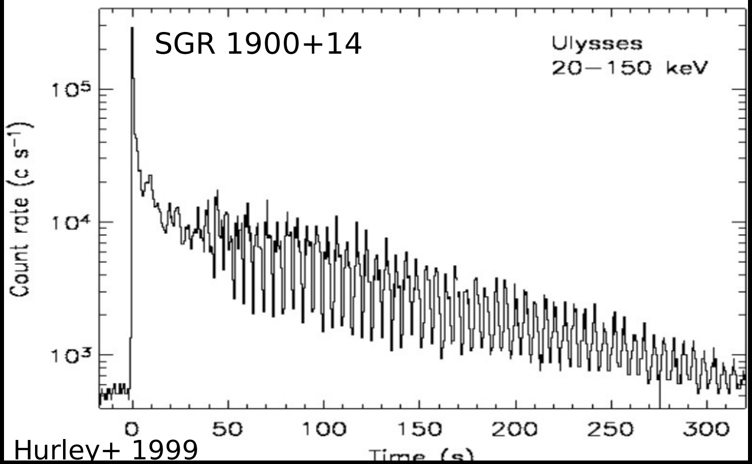
Image credit: E. Gogus



Gotz+ 2006

For reviews Turolla+ 2015; Kaspi & Beloborodov 2017; Esposito+ 2021

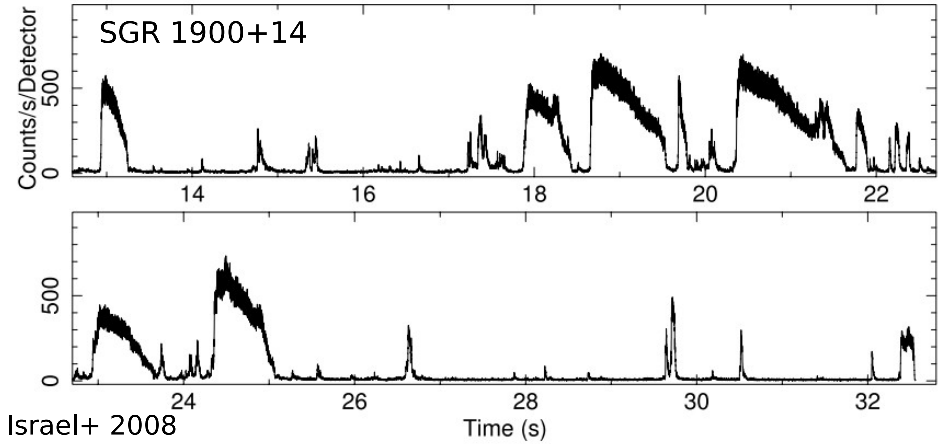
Magnetars: flaring activity – timescale: sec – min



Hurley+ 1999

GIANT FLARES

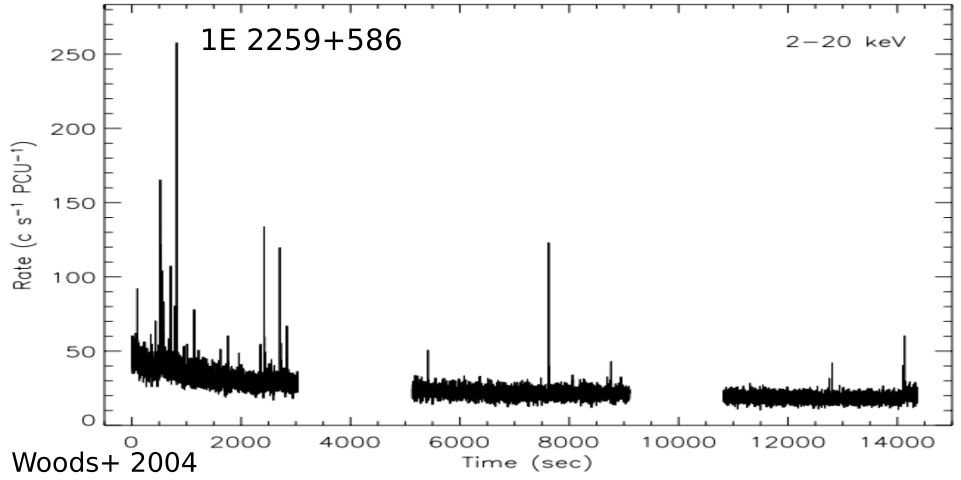
$L_x > 10^{44}$ erg s^{-1}
initial spike with a hard spectrum
+
long pulsating tail modulated at the NS spin period



Israel+ 2008

INTERMEDIATE BURSTS

duration ~ 1 – 40 s
$L_{peak} \sim 10^{41} – 10^{43}$ erg s^{-1}
abrupt onset
thermal spectra

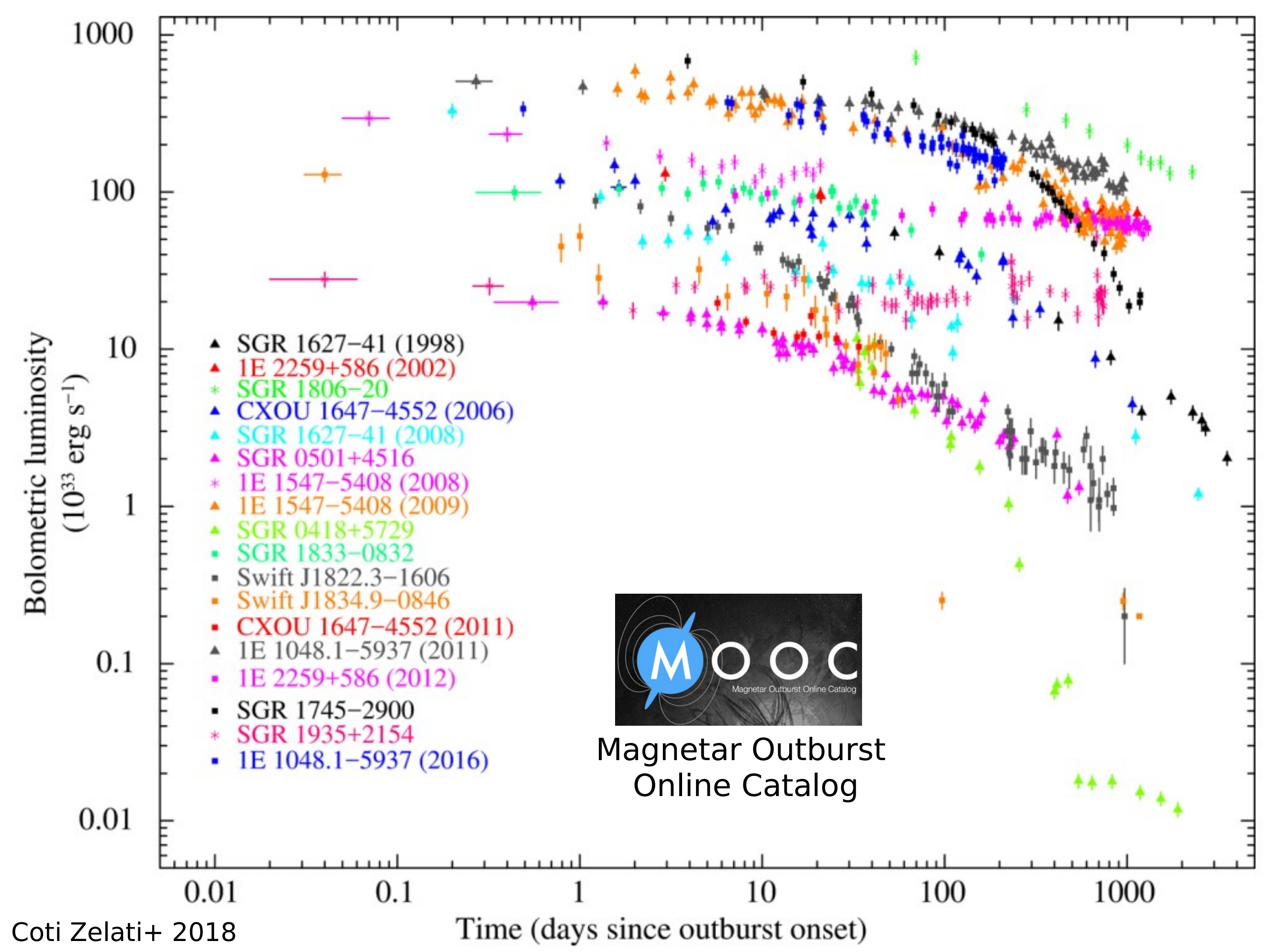


Woods+ 2004

SHORT BURSTS

duration ~ 0.01 – 1 s
$L_{peak} \sim 10^{39} – 10^{41}$ erg s^{-1}
sporadically or storm
thermal spectra

Magnetars: outbursts – timescale: months – years



Magnetar Outburst Online Catalog

Coti Zelati+ 2018

During outbursts

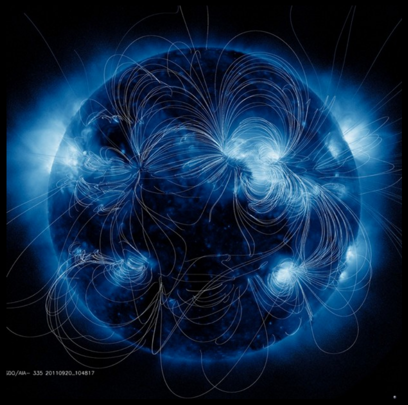
Transient hard X-ray emission

Timing anomalies

Pulsed radio emission (6 cases)

Magnetars: outburst mechanisms

Crustal cooling scenario

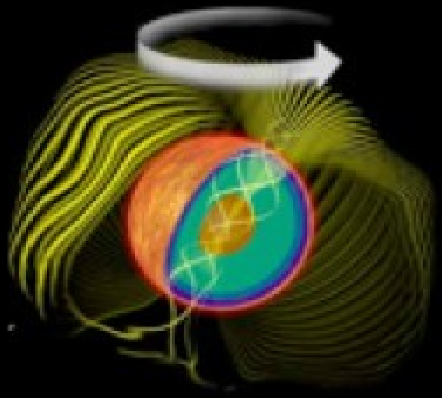


Internal source of heat

Sudden release of heat in the crust due to the long-term building-up of the magnetic stresses

Starquake or thermoplastic waves

Untwisting bundle scenario



External source of heat

Crustal displacements twist the external *B*-field

Ohmic dissipation of currents flowing in a twisted bundle

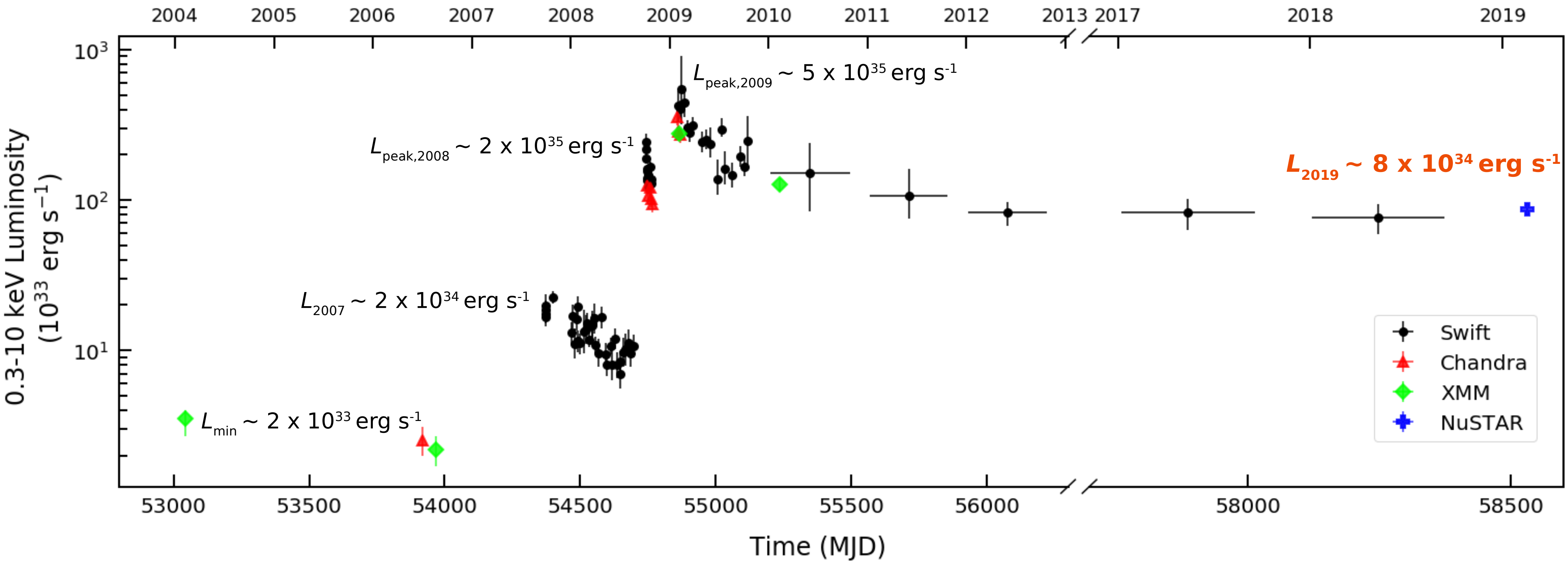
Both processes are likely at work

Nobili, Turolla & Zane 2008a,b; Beloborodov 2009; Pons & Rea 2012; Parfrey+ 2013; Beloborodov & Levin 2014; Beloborodov & Li 2016; Li+ 2016; Li+ 2018; Carrasco+ 2019; De Grandis+ 2020, 2022, Ntotsikas+ 2024

Magnetars: outbursts – a special case

1E 1547.0–5408

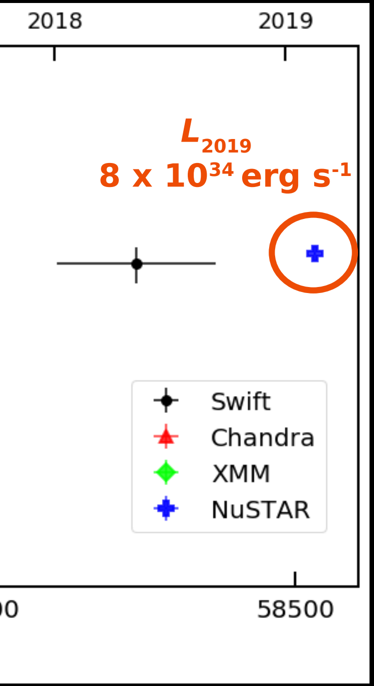
Long-term light curve from Feb 2004 till Feb 2019

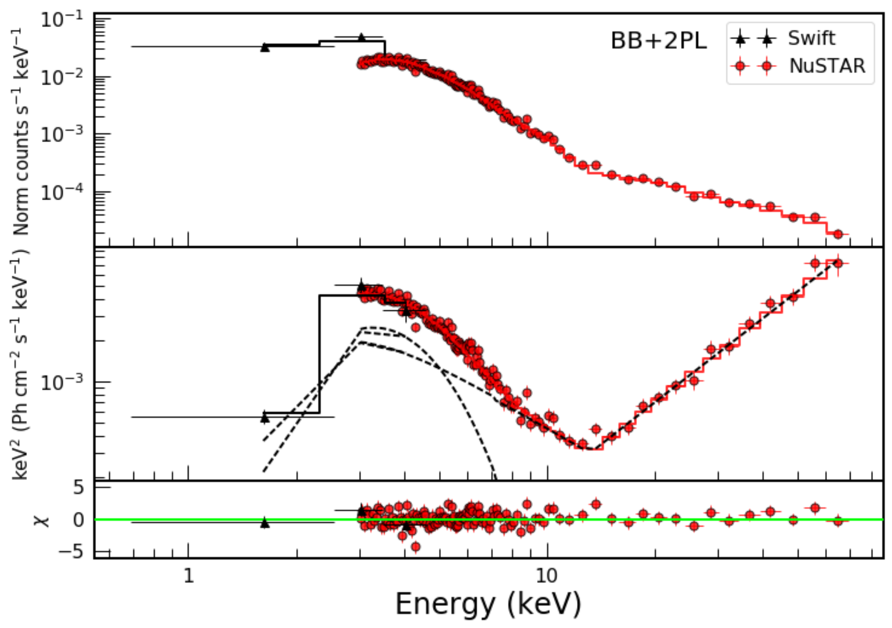


Coti Zelati, Borghese+ 2020

Magnetars: outbursts – a special case

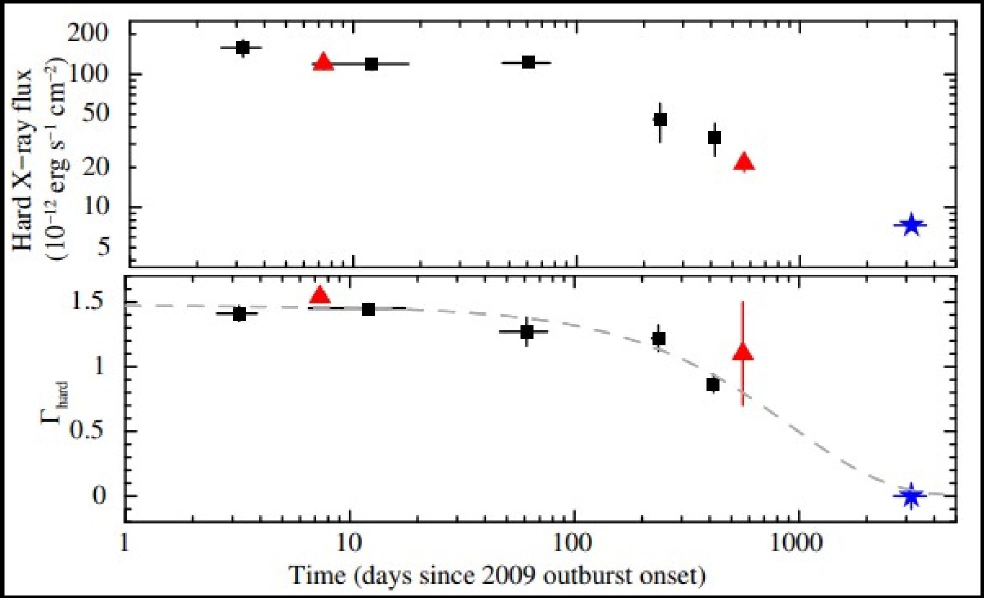
1E 1547.0–5408
Broad-band spectrum on Feb 2019





Hard X-ray emission up to ~70 keV

Lower limit on the high-energy roll-over $E_{cut} > 260$ keV



10-70keV X-ray flux ~7 x 10^{-12} erg s^{-1} cm^{-2} 20x smaller than at the peak

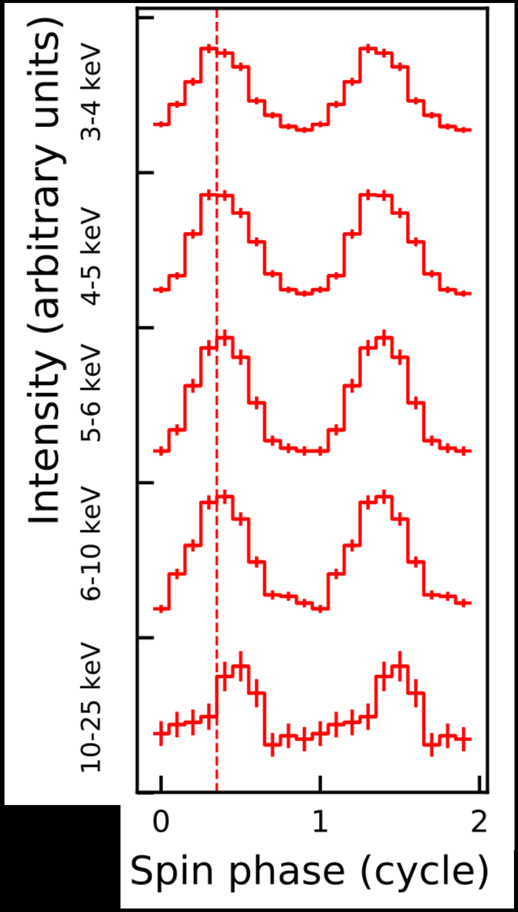
The power law hardened in time

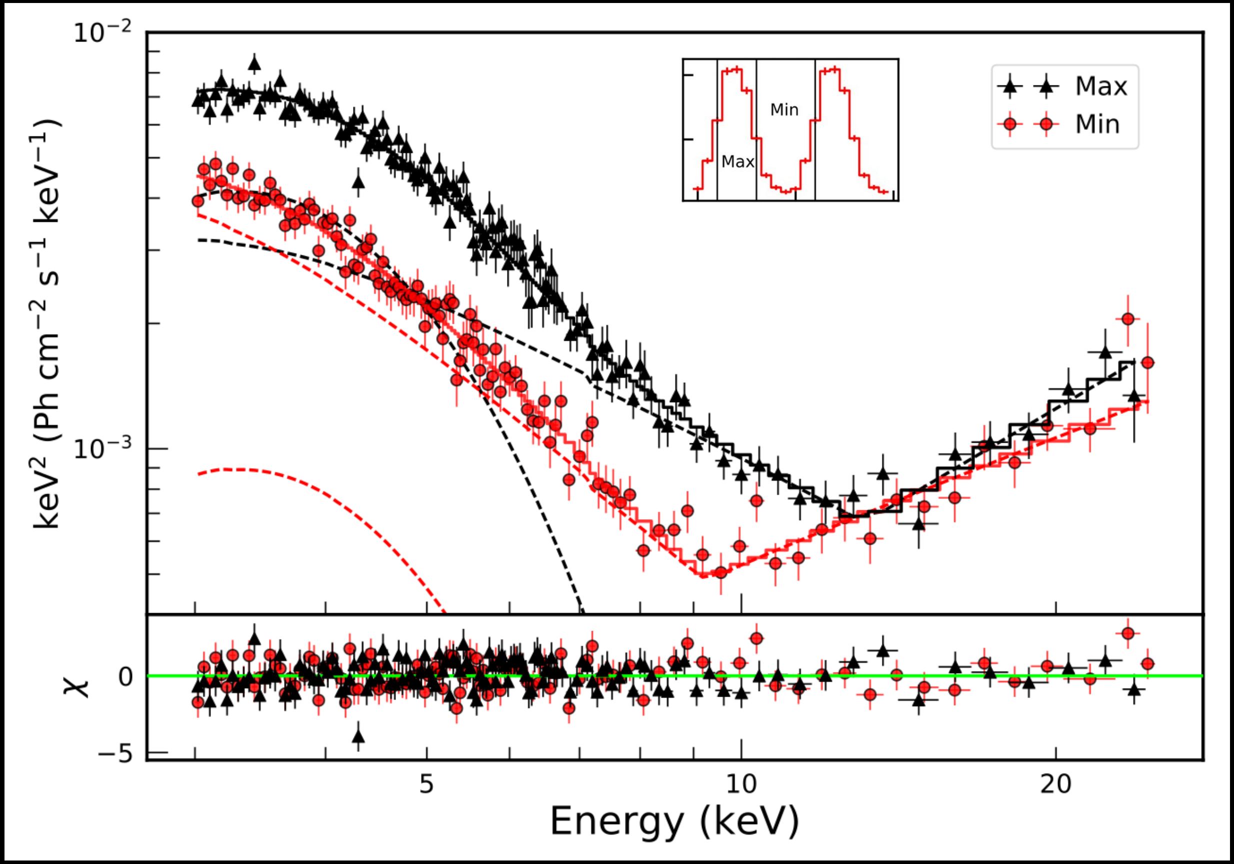
Coti Zelati, Borghese+ 2020

Magnetars: outbursts – a special case

1E 1547.0–5408

Timing analysis and phase-resolved analysis on Feb 2019





Pulsed emission till
~25 keV

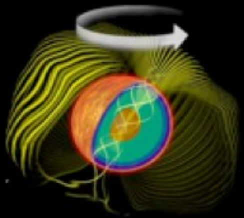
Significant changes

Coti Zelati, Borghese+ 2020

Magnetars: outbursts – a special case

1E 1547.0–5408

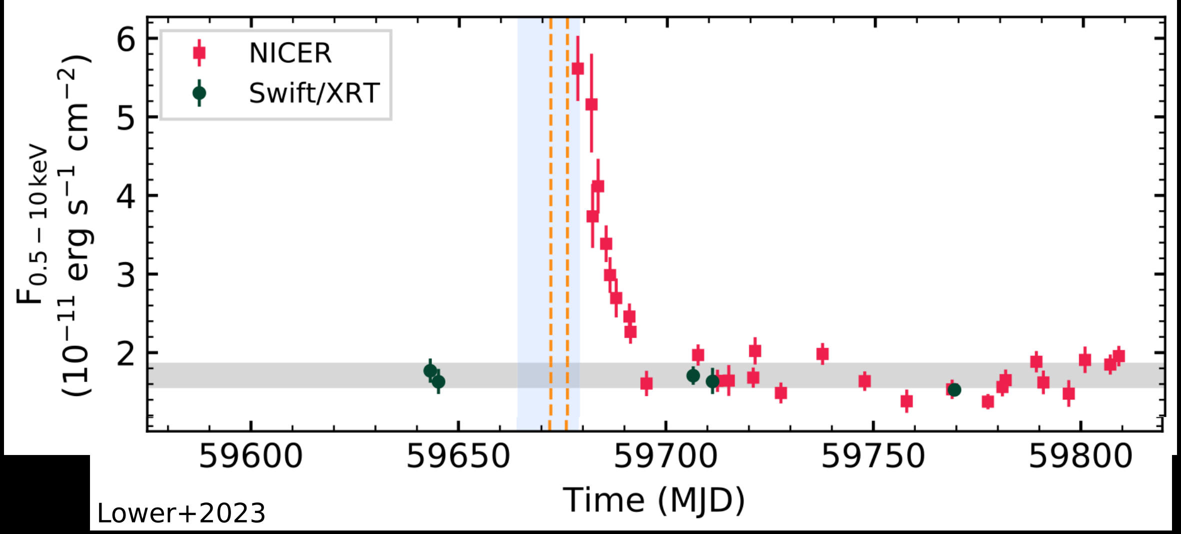
How is it possible to retain a high level of luminosity for such a long time?



New persistent magnetospheric state with long-lived coronal currents
(survival timescale of tens of years)

Currents are responsible for both thermal and non-thermal X-ray emission

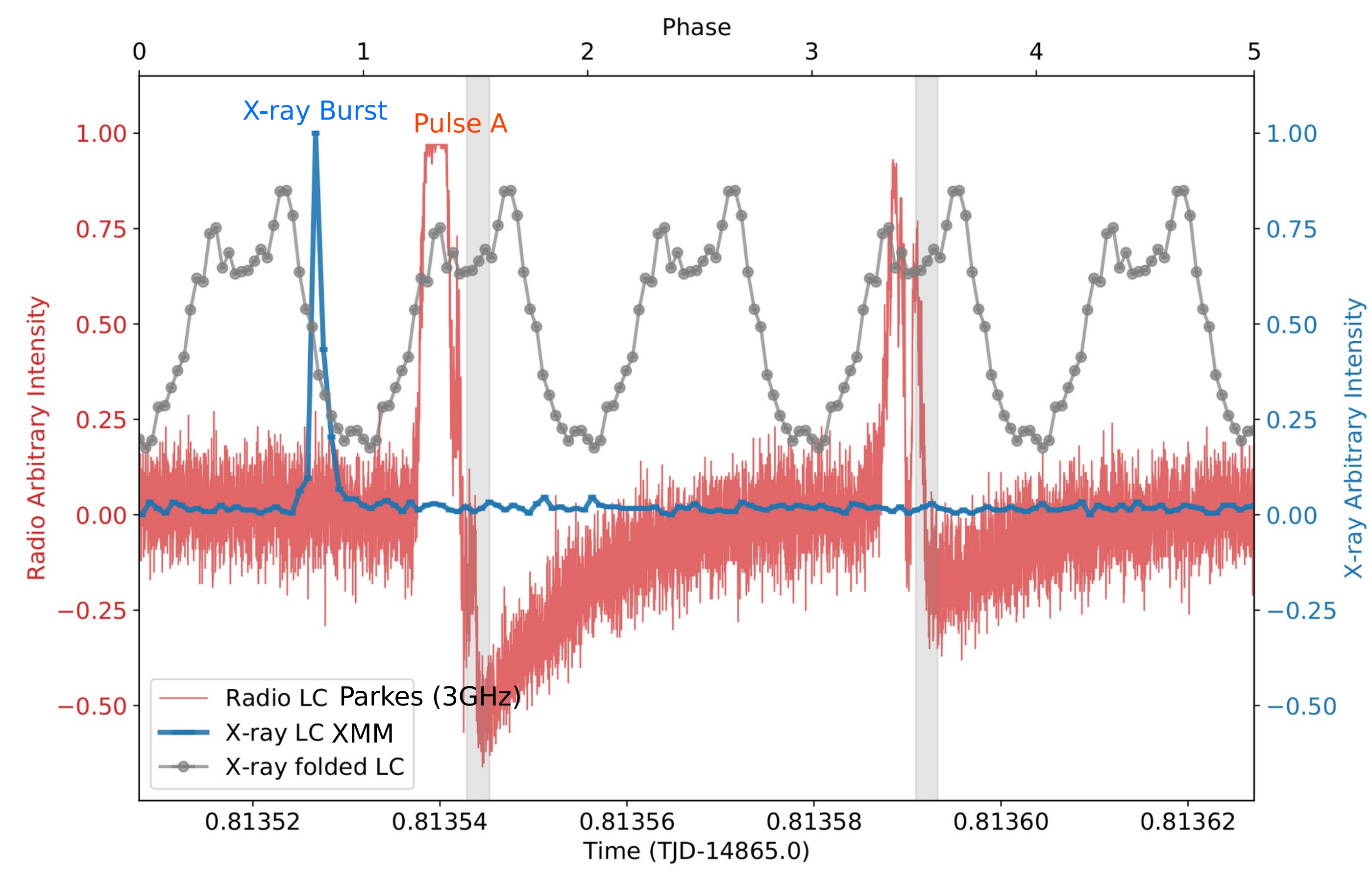
LATEST OUTBURST in April 2022



Lower+2023; Coti Zelati, Borghese+ 2020

Magnetars: outburst – a special case

1E 1547.0–5408
Simoultaneous radio and X-ray observations during the 2009 outburst



Pulse A occurred ~1s after an X-ray burst

Fluence ~ 0.6 kJy ms

Energy ~ 8 x 10^{30} erg

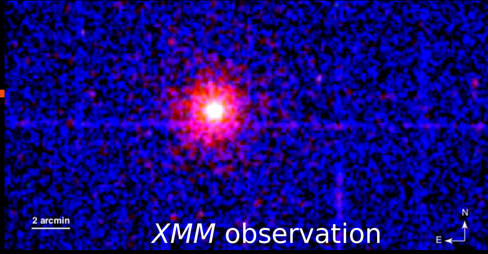
$E_R / E_X \sim 10^{-9}$

SGR 1935: $E_{R,2020} / E_{X,2020} \sim 10^{-5}$

Wide range of radio efficiency → continuum of magnetar radio burst energies

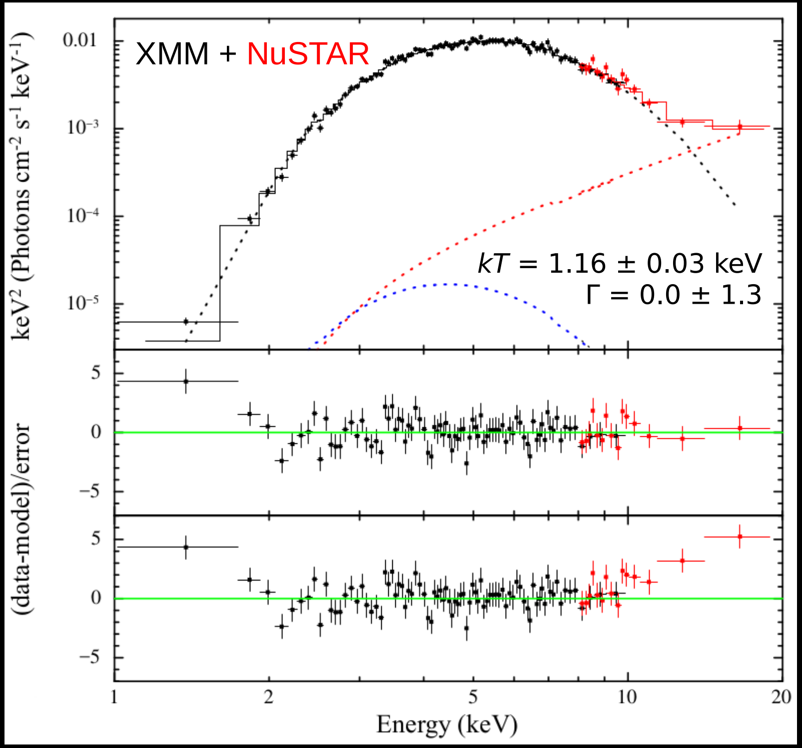
Israel+ 2020

Magnetars: the latest additions



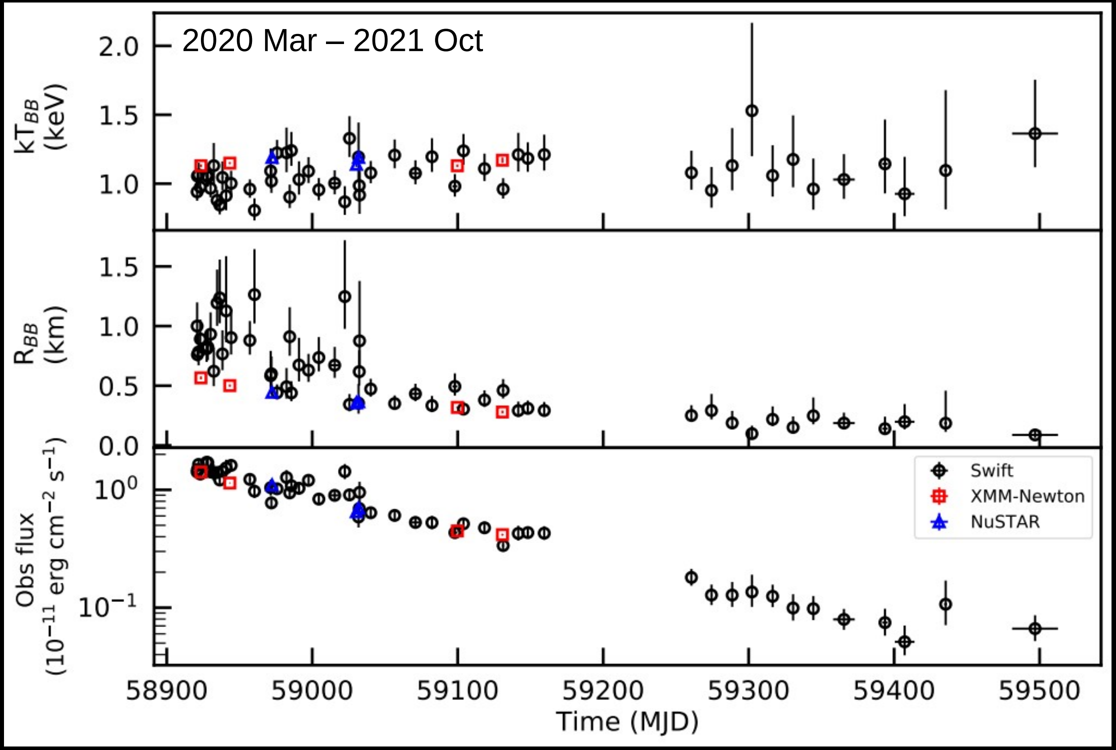
Swift J1818.0–1607
Discovered in outburst in March 2020

3 days after the burst



Standard X-ray spectrum

X-ray monitoring campaign



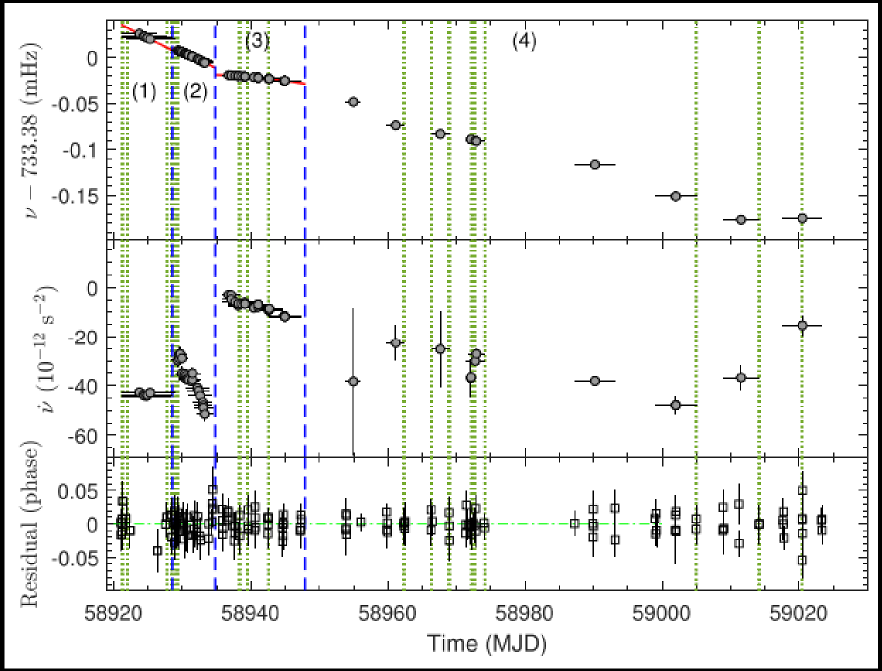
Standard X-ray evolution

Eposito, Rea, Borghese+ 2020; Ibrahim, Borghese+ 2023

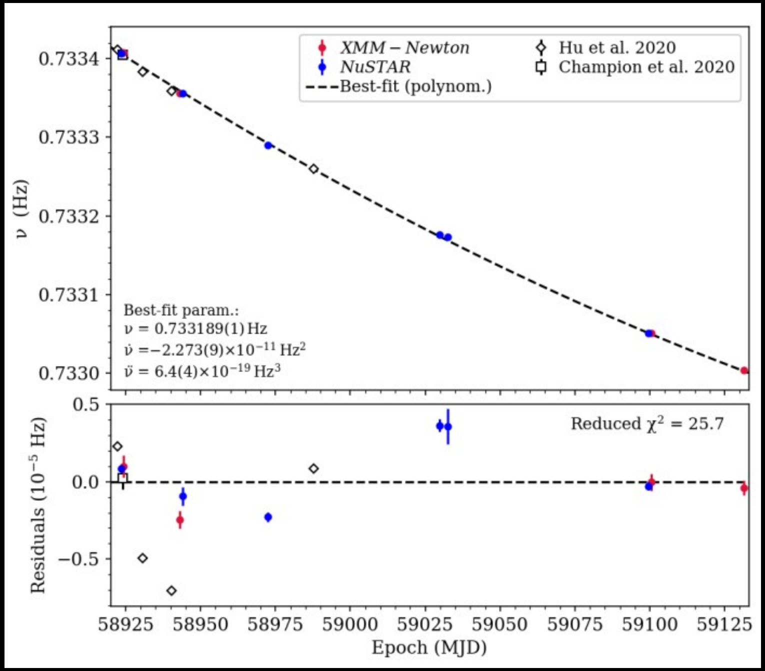
Magnetars: the latest additions

Swift J1818.0–1607
Discovered in outburst in March 2020

NICER campaign for the first 100 days



XMM+NuSTAR over the first 7 months



Erratic timing behaviour
***P* ~ 1.36 s**
Pdot ~ 4.6x10^{-11} s s^{-1}

τ_c ~ 500 yr
B_{dip} ~ 2.5x10^{14} G
Edot ~ 7.2x10^{35} erg s^{-1}

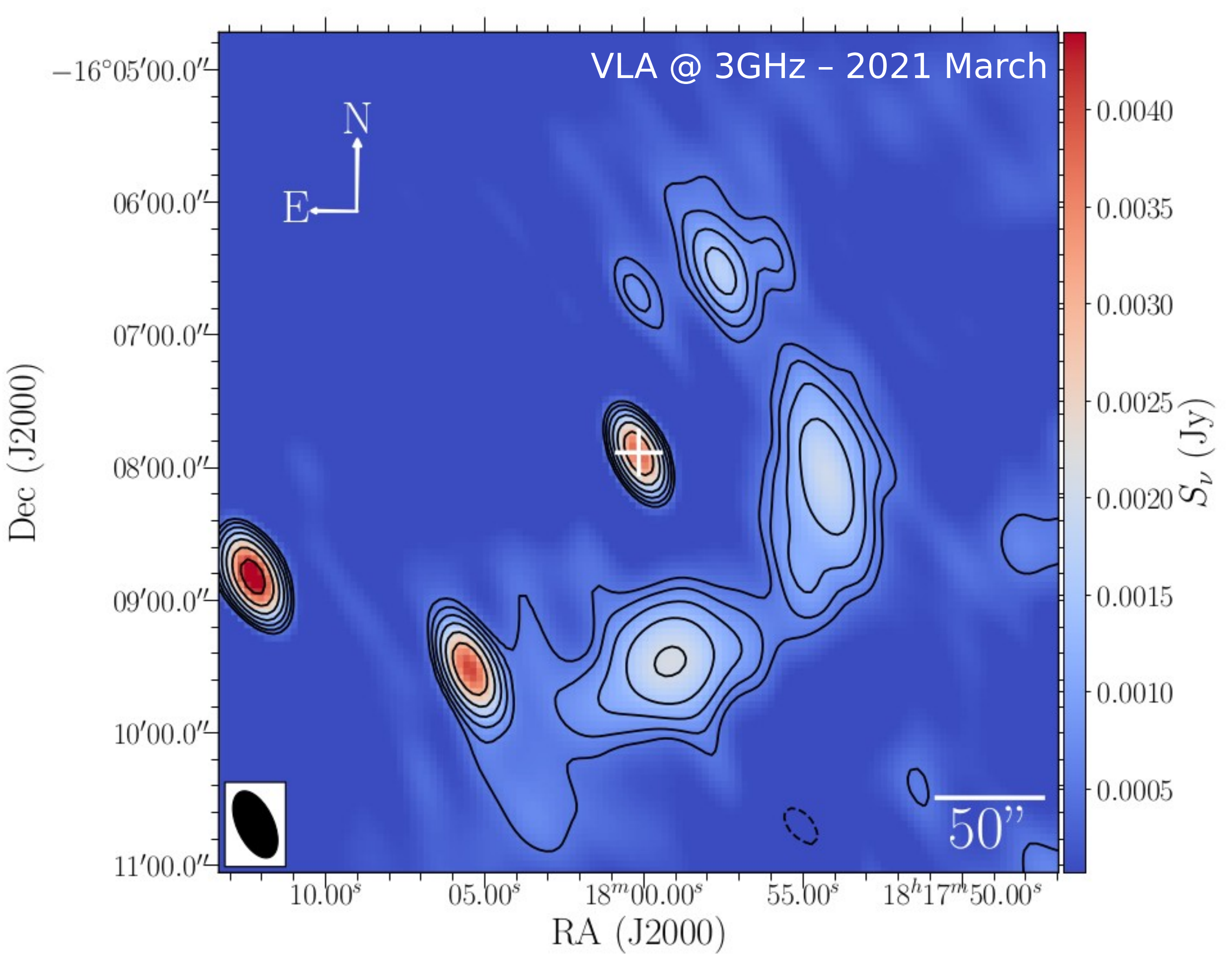
One of the youngest NSs in our Galaxy

Hu+ 2020; Ibrahim, Borghese+ 2023

Magnetars: the latest additions

Swift J1818.0–1607
Discovered in outburst in March 2020

Search for the supernova remnant



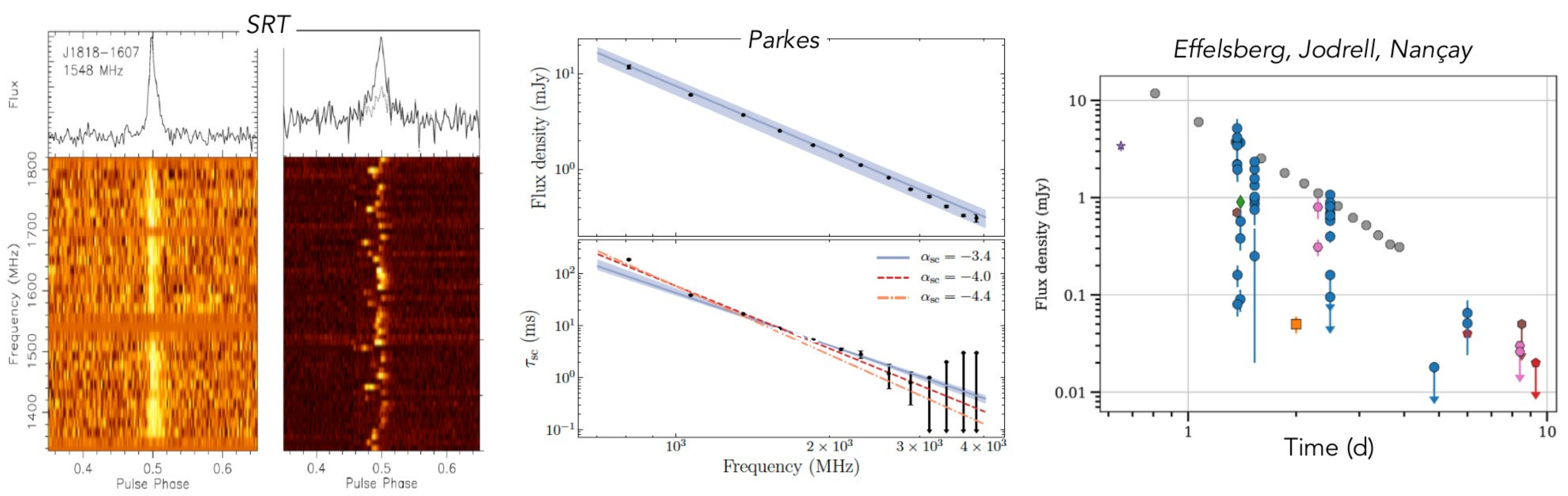
One of the youngest NSs in our Galaxy

Ibrahim, Borghese+ 2023

Magnetars: the latest additions

Swift J1818.0–1607
Discovered in outburst in March 2020

Soon confirmed to be a radio-loud magnetar



Bright single pulses

Peculiar steep spectral slope

Rapid radio flux decay

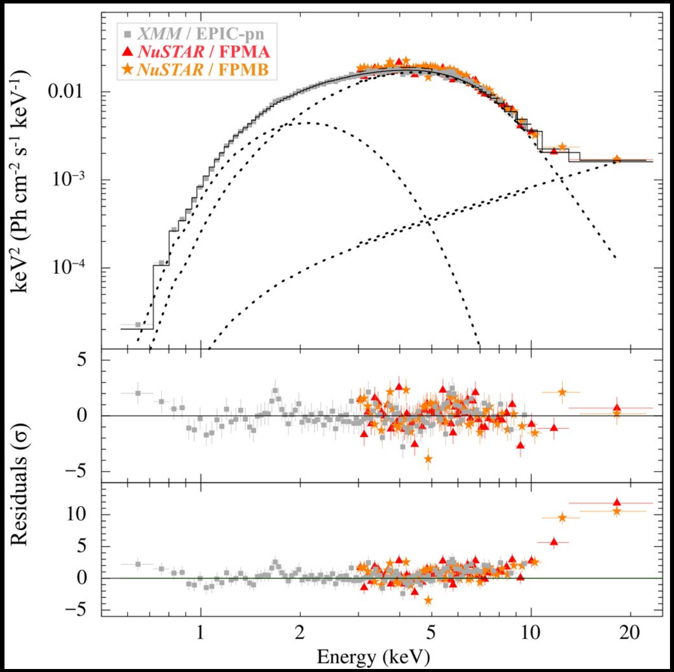
The young age, the high spin-down luminosity and the steep radio spectrum resemble those of RPPs

Link between magnetars and rotation-powered pulsars

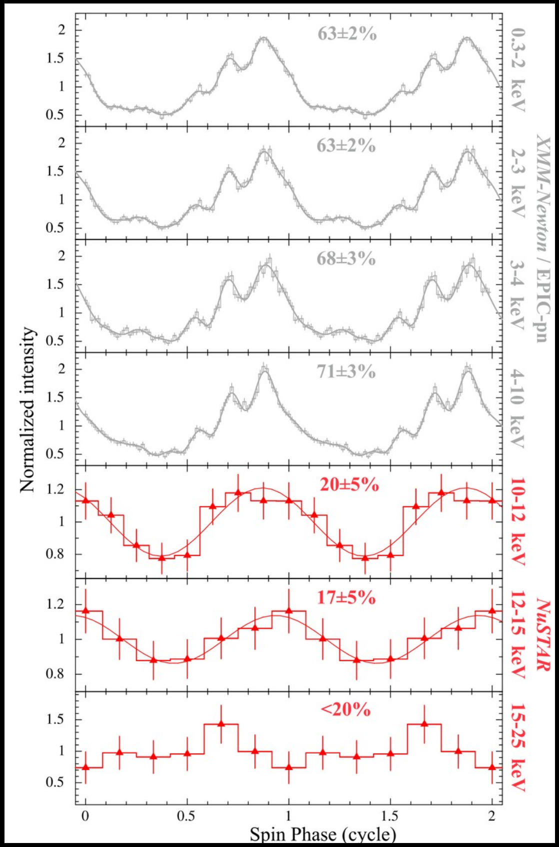
Esposito+ 2020; Champion+ 2020; Lower+ 2020, 2021; Huang+ 2021

Magnetars: the latest additions

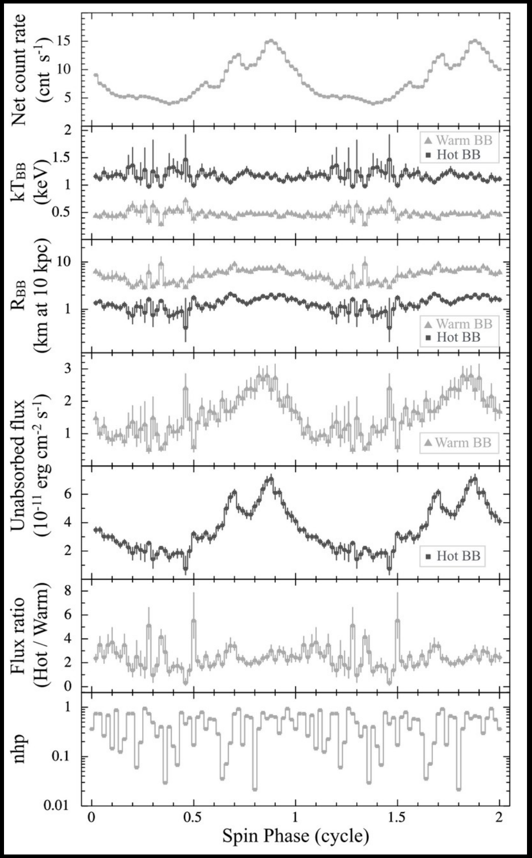
SGR 1830–0645
Discovered in outburst in October 2020



Mostly thermal spectrum plus a faint PL tail



Complex morphology at low energy



Phase-resolved analysis

Single heated spot with a complex shape: extended warm region surrounded by a smaller hotter region

Coti Zelati, Borghese+ 2021; see also Younes+ 2022a,b

Magnetars: the latest additions

Swift J1555.2–5402
Discovered in outburst in June 2021

NICER discovery of 3.86 s pulsations from a new magnetar: SGR J1555.2-5402

ATel #14674; *F. Coti Zelati, A. Borghese, N. Rea (ICE-CSIC), G. L. Israel (INAF-OAR), P. Esposito (IUSS Pavia), T. Enoto (RIKEN), K. Gendreau (NASA/GSFC) S. Campana (INAF-OAB) on behalf of a larger collaboration*
*on **3 Jun 2021; 16:33 UT***

Daily NICER observations over 1 month

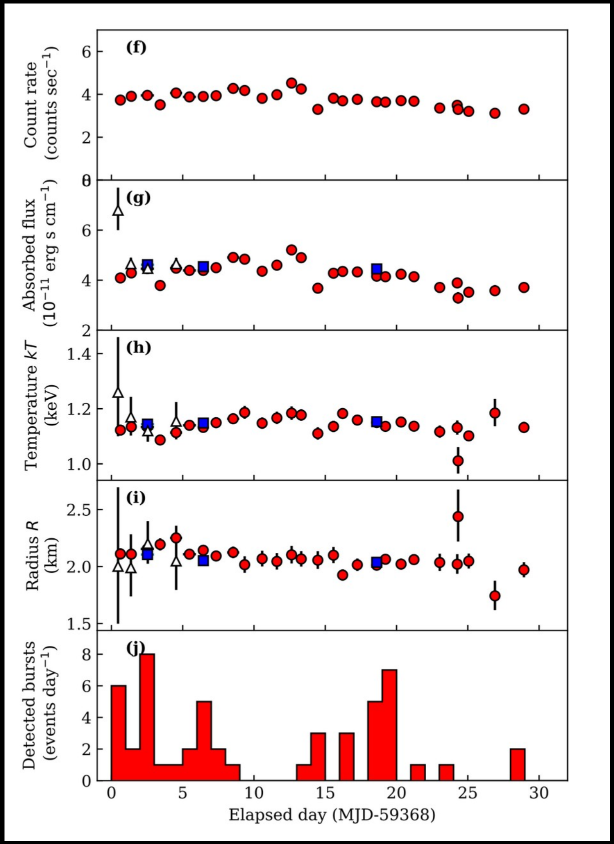
Nearly constant flux at $\sim 4 \times 10^{-11}\ \mathrm{erg\ s^{-1}\ cm^{-2}}$

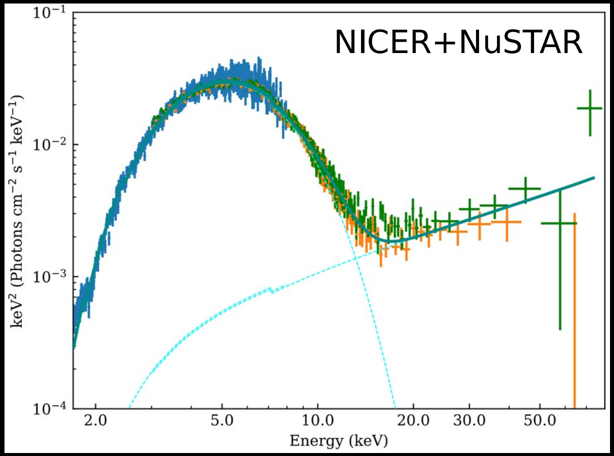
Thermal spectrum

Several X-ray bursts

Emission up to ~40 keV

Pdot $\sim 3 \times 10^{-11}\ \mathrm{s\ s^{-1}}$ (large timing noise)
$B_{dip} \sim 3.5 \times 10^{14}$ G
Edot $\sim 2 \times 10^{34}\ \mathrm{erg\ s^{-1}}$
$T_c \sim 2$ kyr





Enoto+ 2021; Borghese+ in prep.

We observed magnetar-like activity from non-canonical magnetars

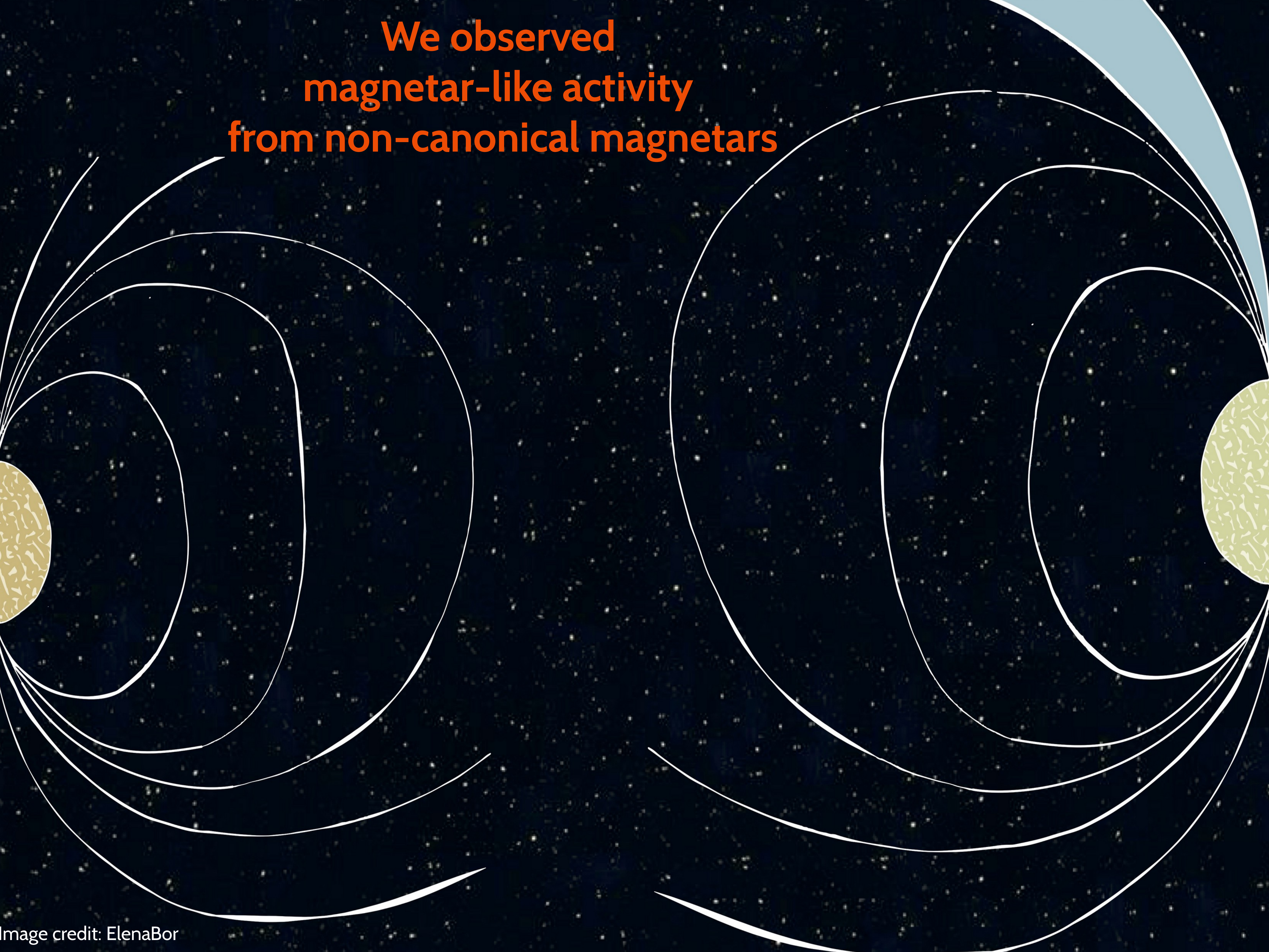
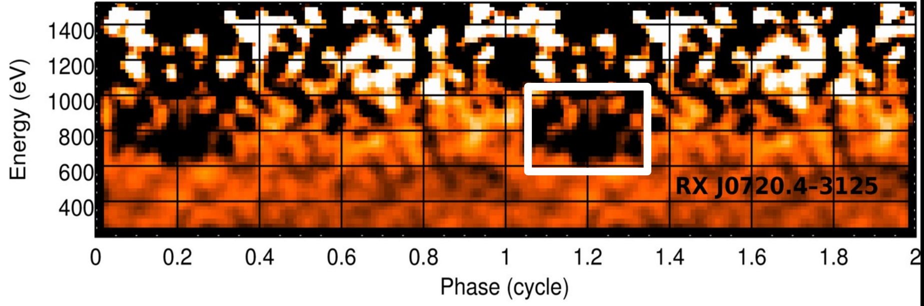
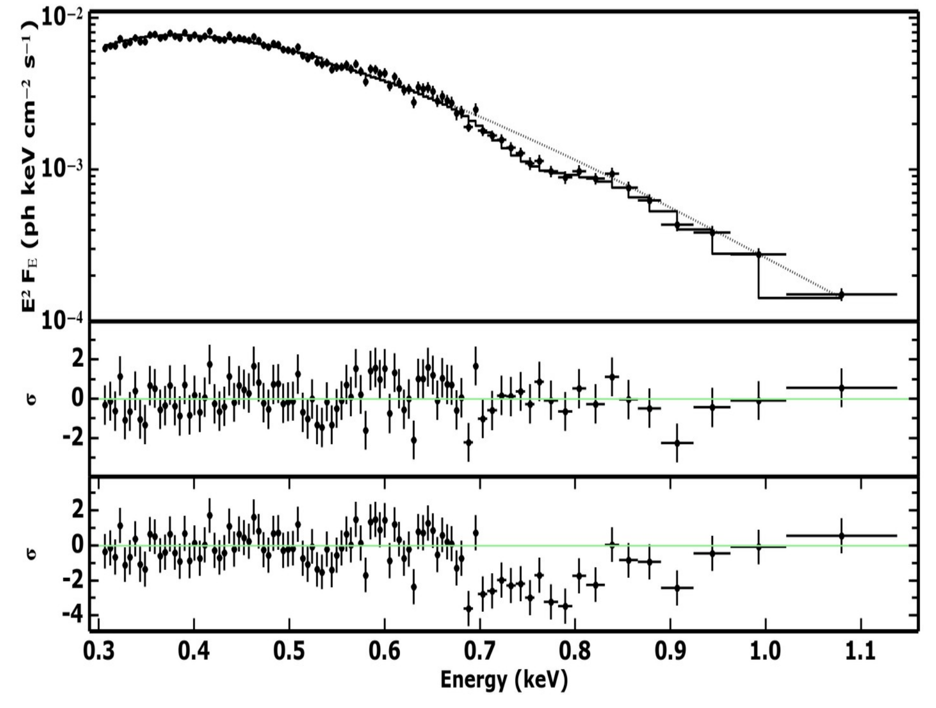


Image credit: ElenaBor

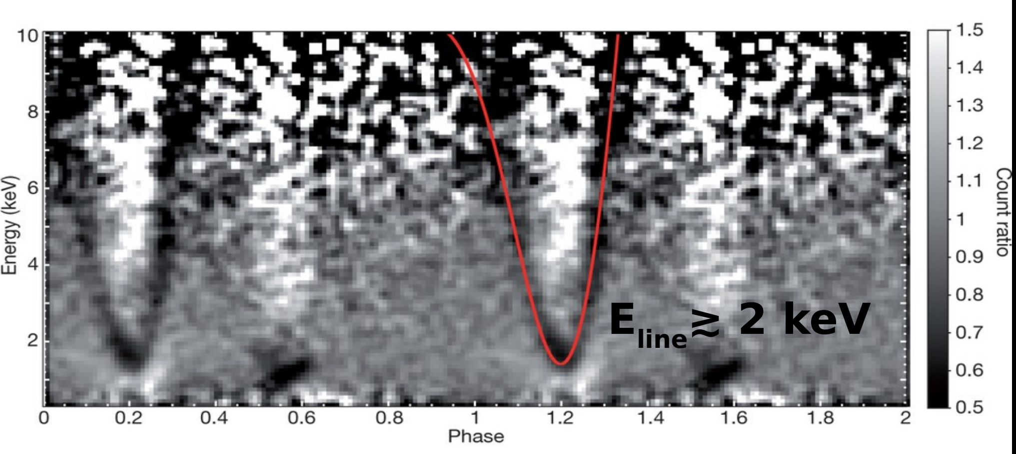
Magnetar-like activity from non-canonical magnetars

X-RAY DIM ISOLATED NEUTRON STARS
as old magnetars





the low-*B* magnetar
SGR 0418+5729

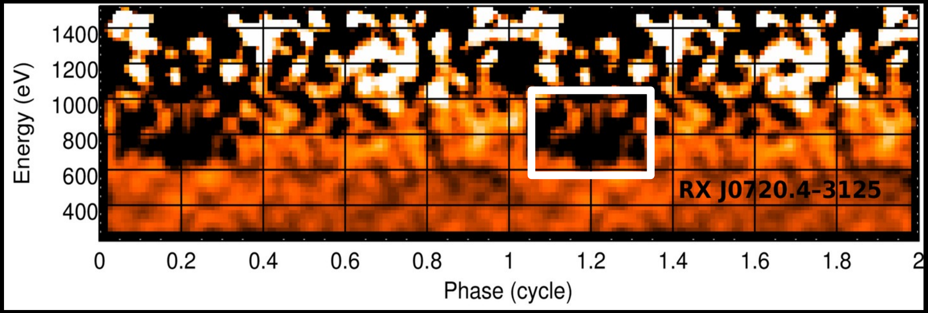


$P = 9.1$ s
Pdot = 4×10^{-15} s s^{-1}

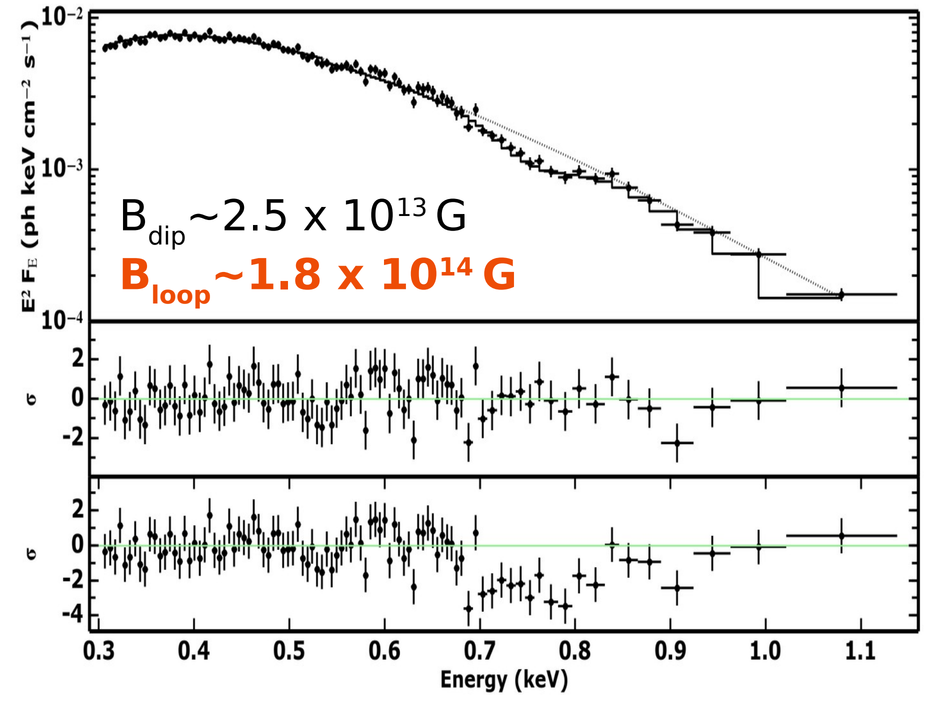
$B_{dip} = 6 \times 10^{12}$ G
$\tau = 35$ Myr

Borghese+ 2015, 2017

X-RAY DIM ISOLATED NEUTRON STARS
as old magnetars



Proton cyclotron resonant scattering



$B_{dip} \sim 2.5 \times 10^{13}$ G

$B_{loop} \sim 1.8 \times 10^{14}$ G

First observational evidence for a complex magnetic field in the XDINSs

Evolutionary connection between XDINSs and magnetars

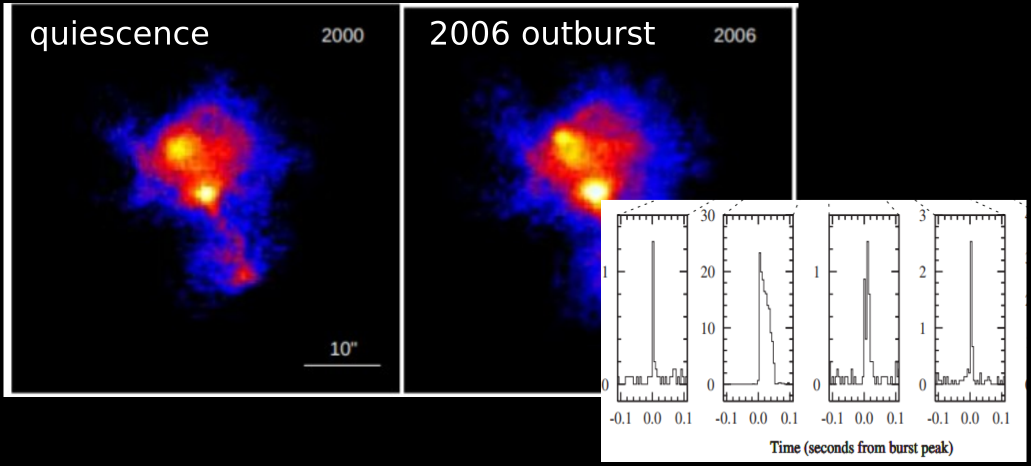
Borghese+ 2015, 2017

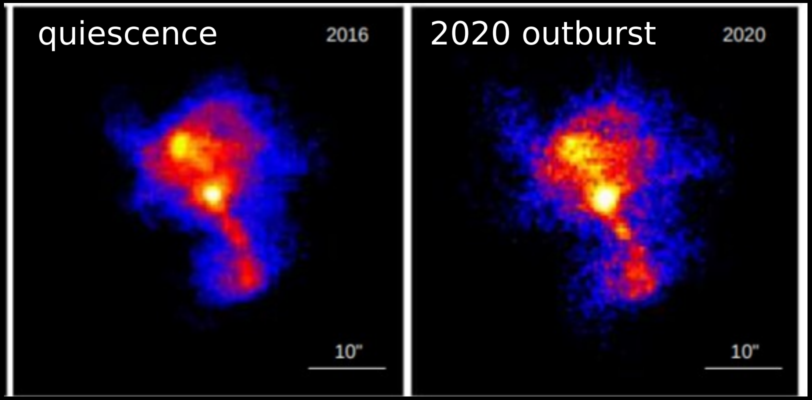
Magnetar-like activity from non-canonical magnetars

HIGH-B ROTATION POWERED PULSARS

PSR J1846-0258

at the center of the SNR Kes75 with $B_{dip} \sim 5 \times 10^{13}$ G

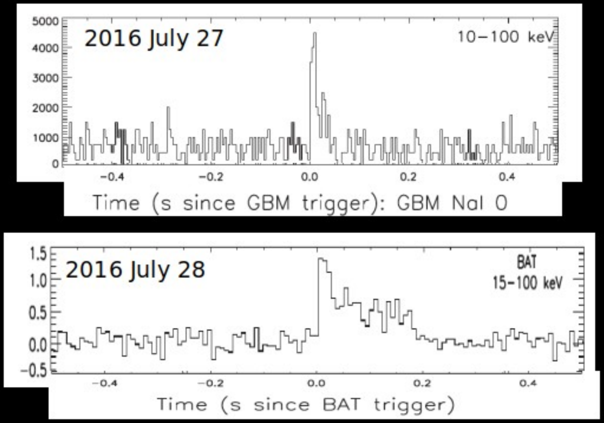




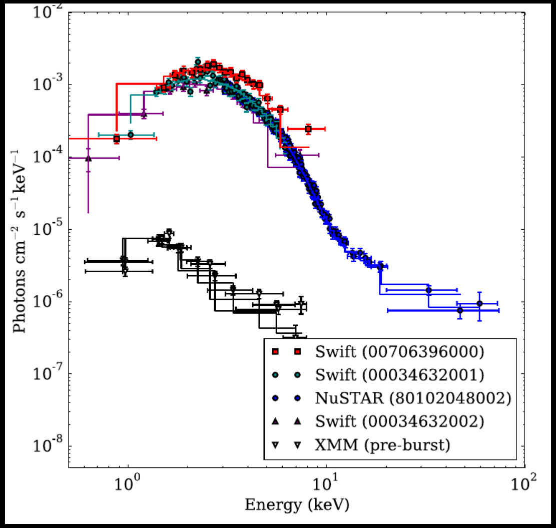
Gavriil+ 2008; Kumar & Safi-Harb 2008; Blumer+ 2021; Sathyaprakash+ 2024 subm.

PSR J1119-6127

with $B_{dip} \sim 4 \times 10^{13}$ G



Two magnetar-like bursts marked the onset of the outburst



Archibald+ 2016, 2017; Gogus+ 2016

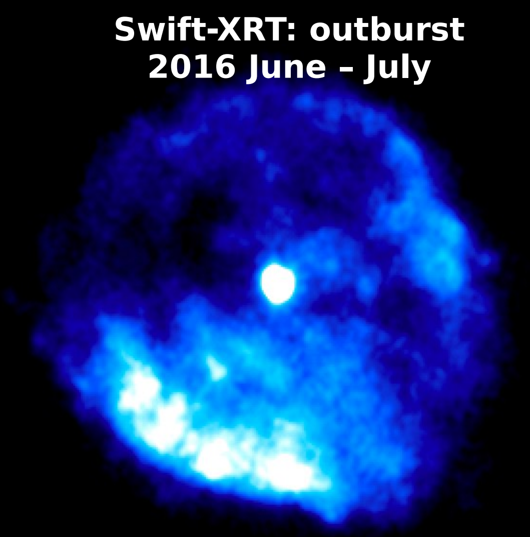
Magnetar-like activity from non-canonical magnetars

CENTRAL COMPACT OBJECTS

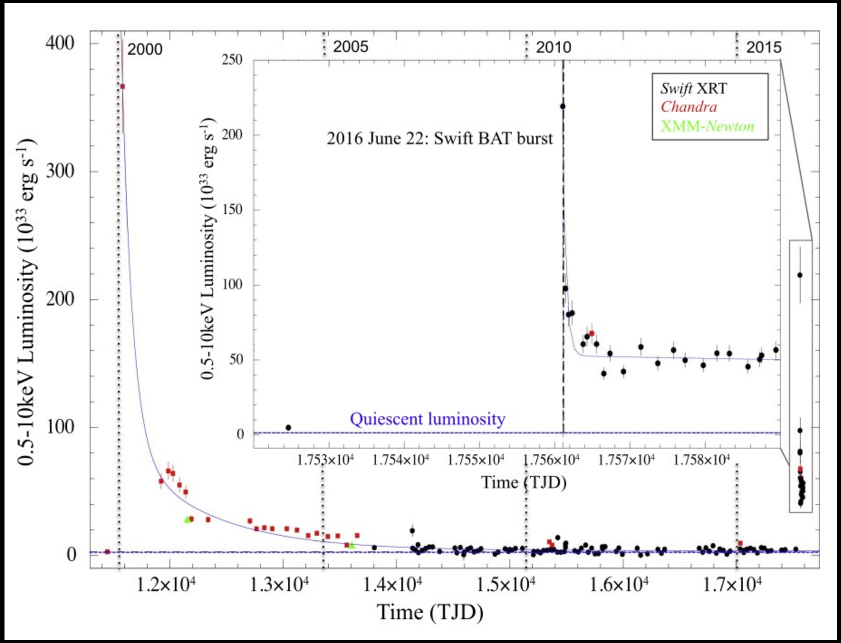
1E 161348-5055

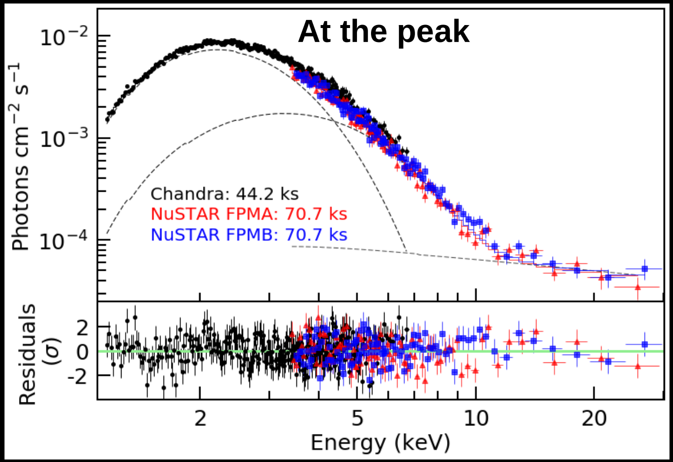
at the center of the SNR RCW103 with *P* ~ 6.67 h and age ~ 2ky

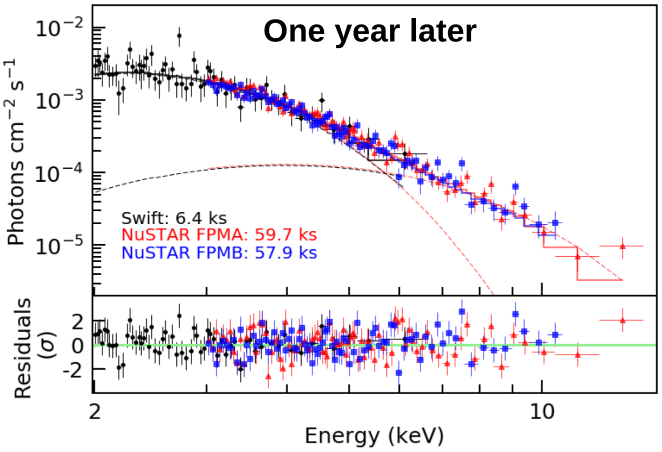
Swift-XRT: quiescence
2011 April – 2016 May



Swift-XRT: outburst
2016 June – July







Magnetar-like outbursts in 1999 and 2016

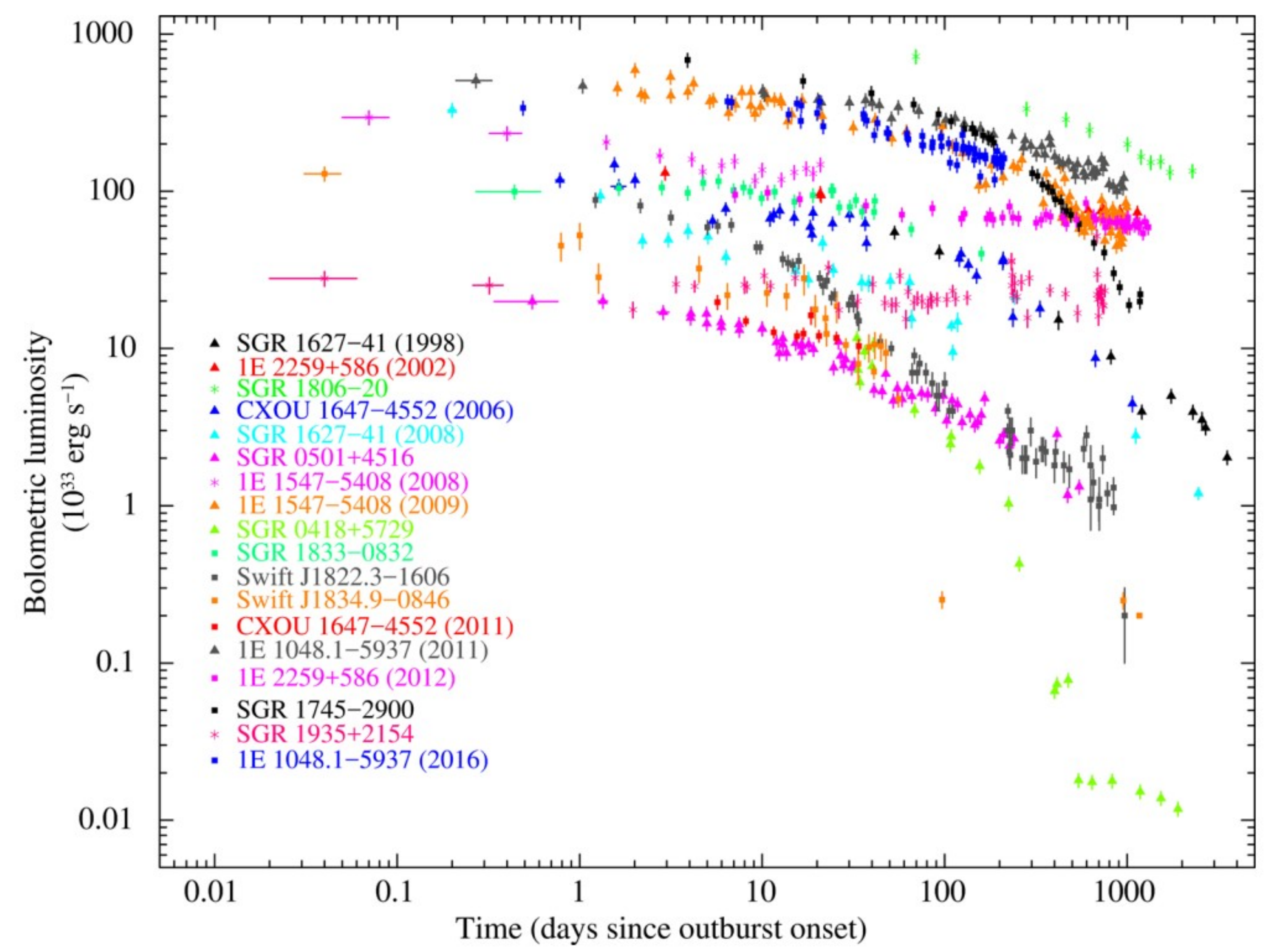
Magnetar-like spectrum with the appearance of a hard X-ray component

Rea, Borghese+ 2016; D'Ai'+ 2018; Borghese+ 2018

Magnetar Outburst Online Catalog

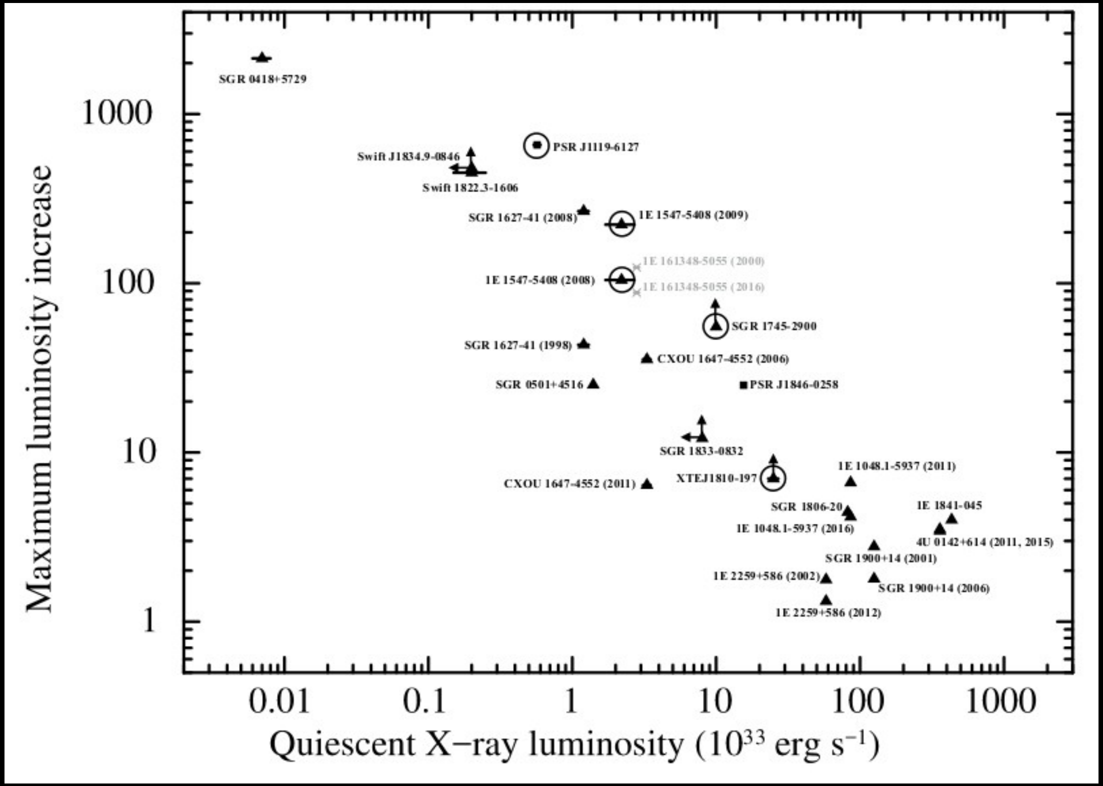
23 outbursts from 14 magnetars + 2 high-B RPPS + CCO in RCW 103

1100 X-ray observations (12 Ms) from 1998 to 2016



Coti Zelati+ 2018

Magnetar Outburst Online Catalog



Large flux enhancement can only be observed in faint quiescent magnetars

Limiting peak luminosity ~10^{36} erg s^{-1}

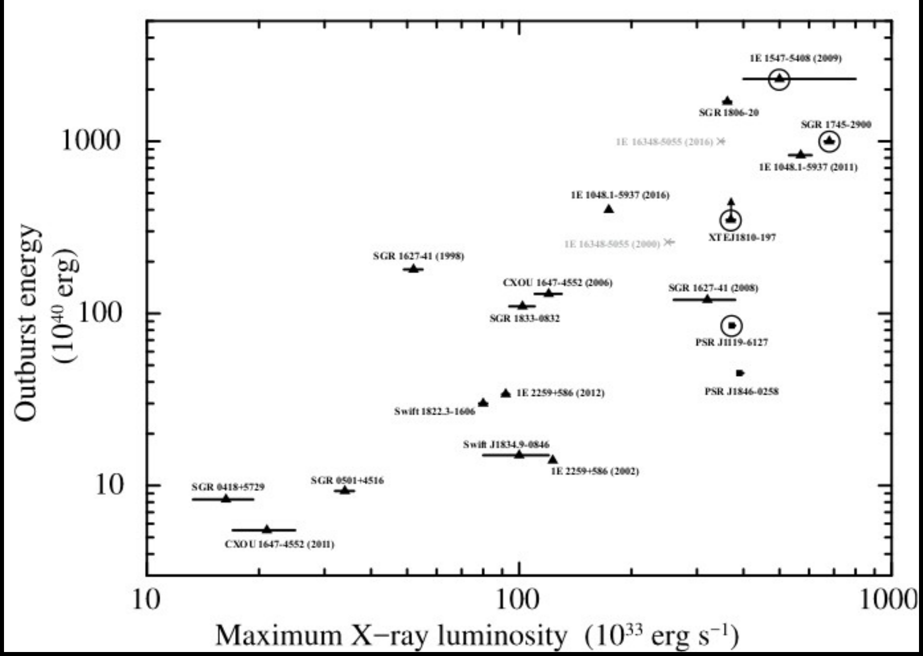
Crustal cooling scenario:
observational manifestation of the self-regulating effect resulting from the strong temperature-dependence of the neutrino emissivity

Untwisting bundle scenario:
maximum theoretically luminosity ~ few 10^{36} erg/s
for a global twist with twist angle ~1 rad

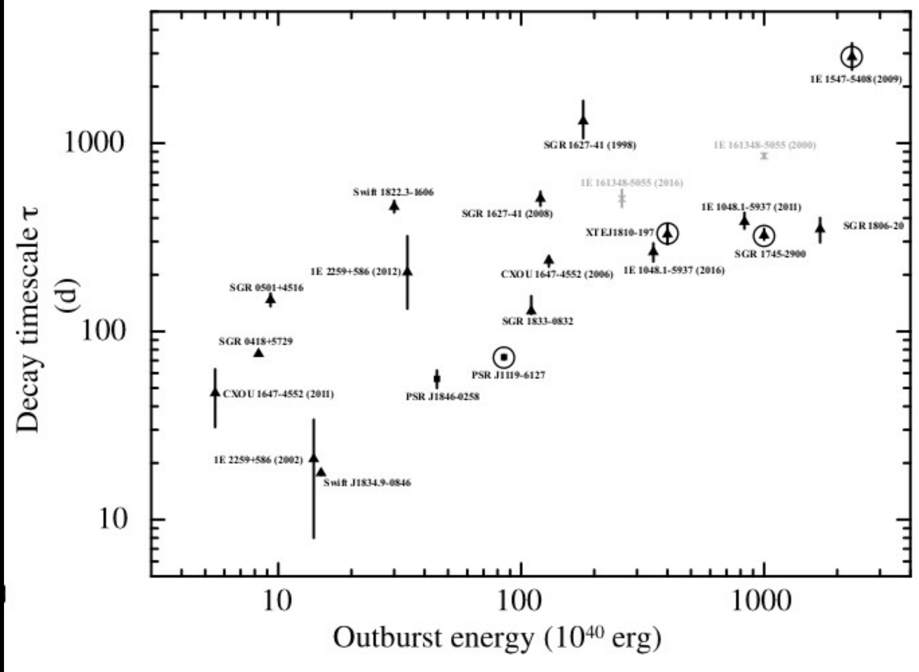
lower values observed because of the small twisted region
(narrow bundle from a small hot spot)

Coti Zelati+ 2018

Magnetar Outburst Online Catalog



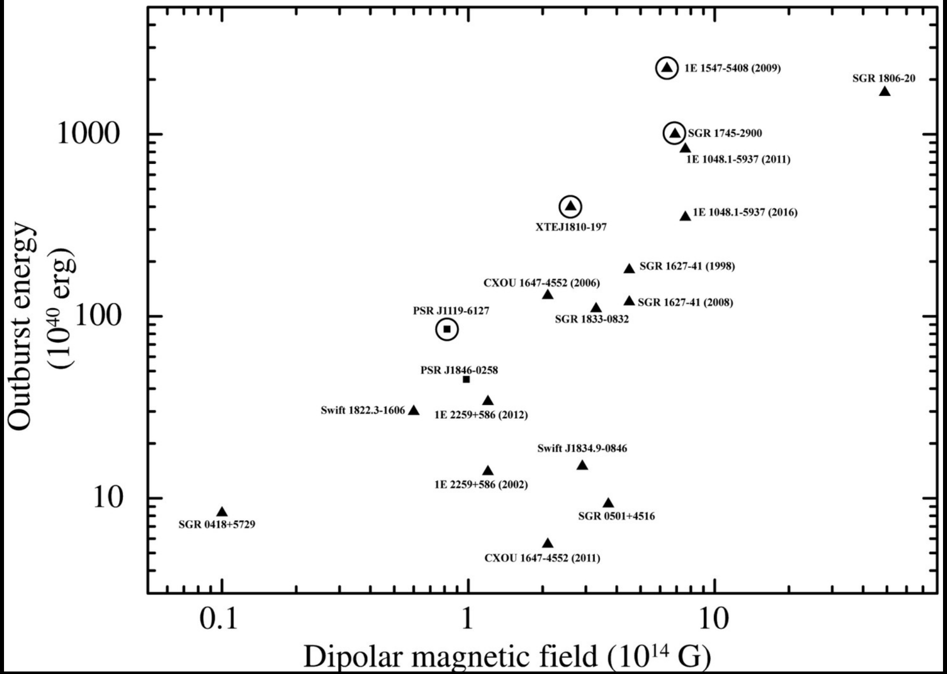
Larger luminosity at the peak
=
Larger energy released



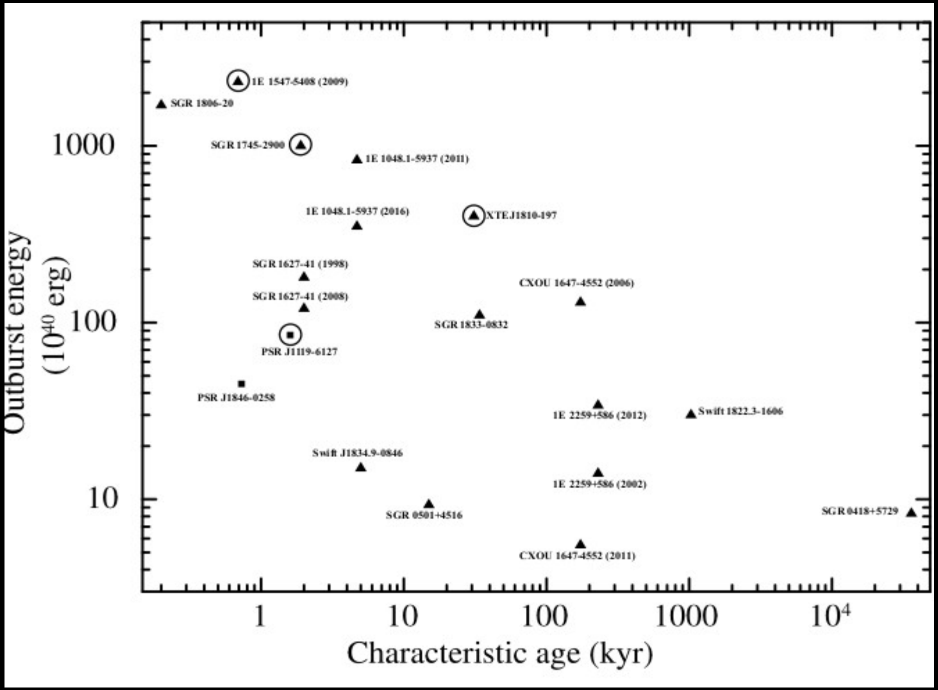
Longer the outburst,
the more energetic

Coti Zelati+ 2018

Magnetar Outburst Online Catalog



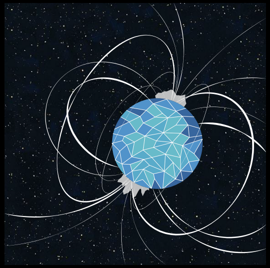
Energy reservoir of the outburst
=
Dissipation of the magnetic field



Young magnetars tend to experience more energetic outbursts than older ones

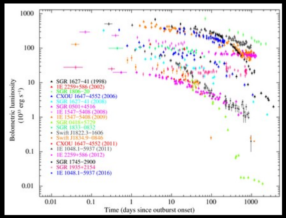
Coti Zelati+ 2018

Take-home messages



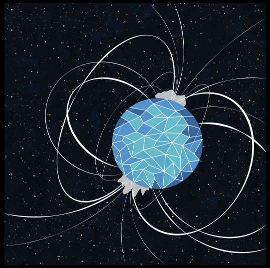
Dedicated observing campaigns of magnetars are crucial to understand emission mechanisms and discover peculiar sources

Magnetar-like activity occurs in isolated neutron stars with a wide range of magnetic field



A new version of the Magnetar Outburst Online Catalog will be released soon...**STAY TUNED!!!**

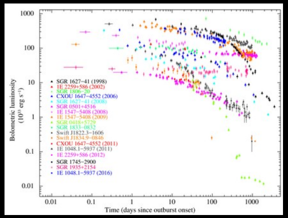
Take-home messages



Dedicated observing campaigns of magnetars are crucial to understand emission mechanisms and discover peculiar sources

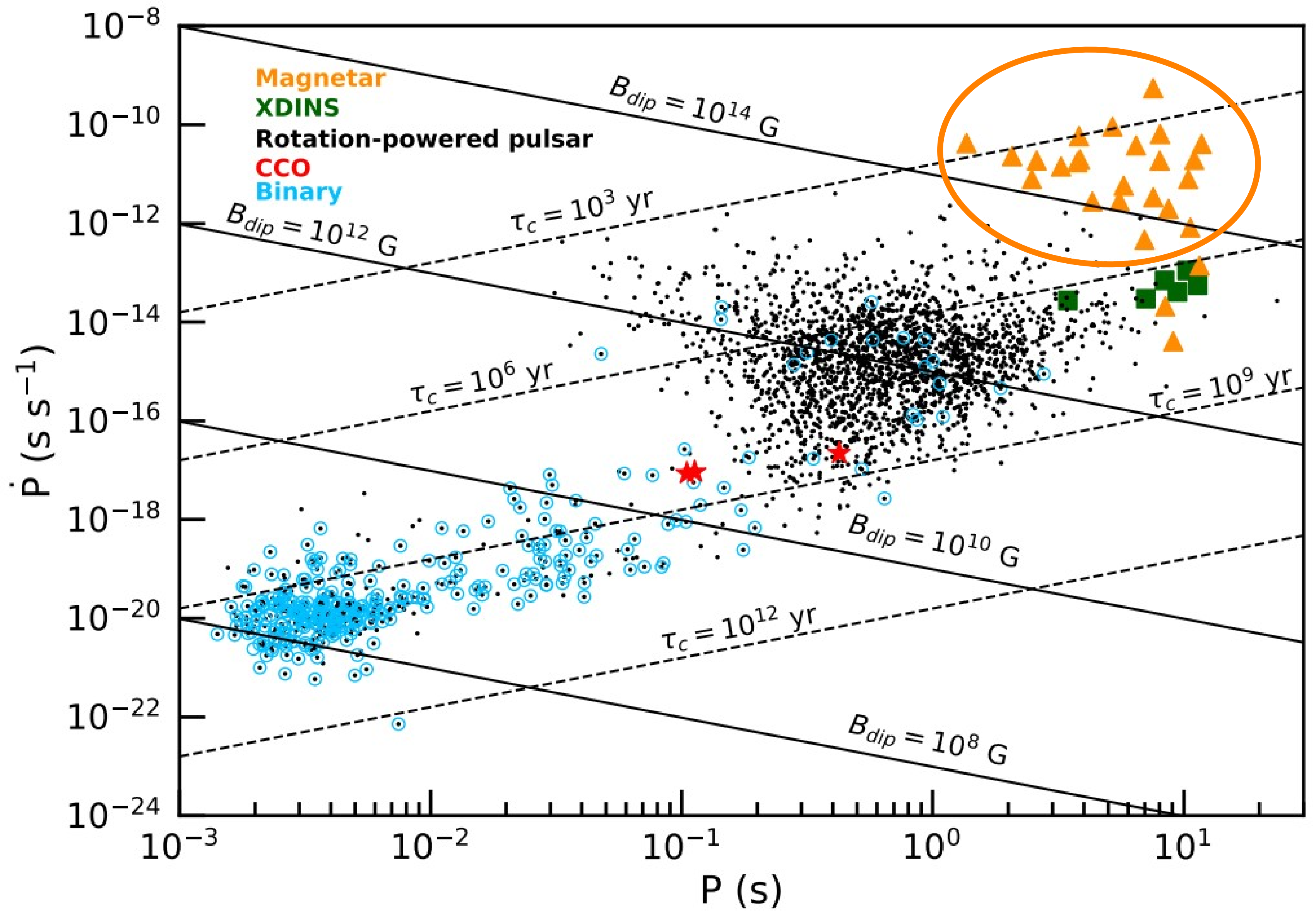
Magnetar-like activity occurs in isolated neutron stars with a wide range of magnetic field

THANK YOU



A new version of the Magnetar Outburst Online Catalog will be released soon...**STAY TUNED!!!**

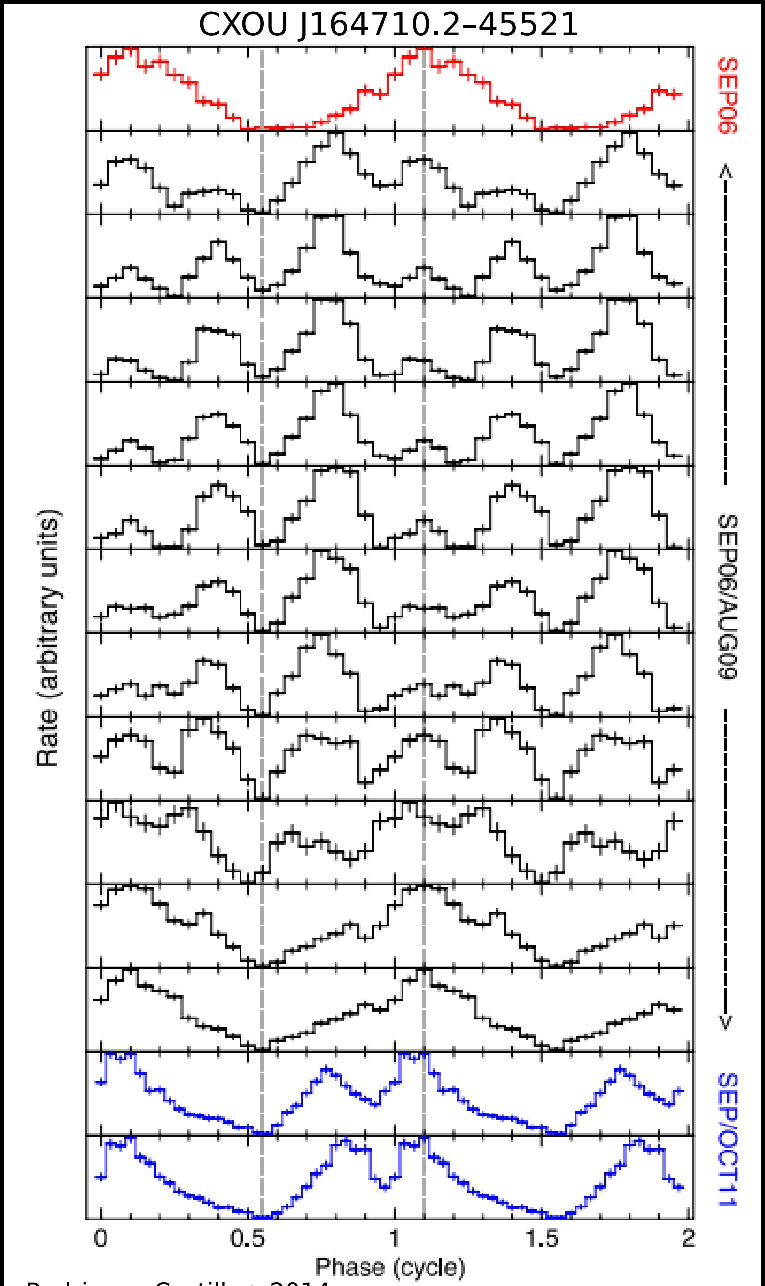
P-Pdot diagram



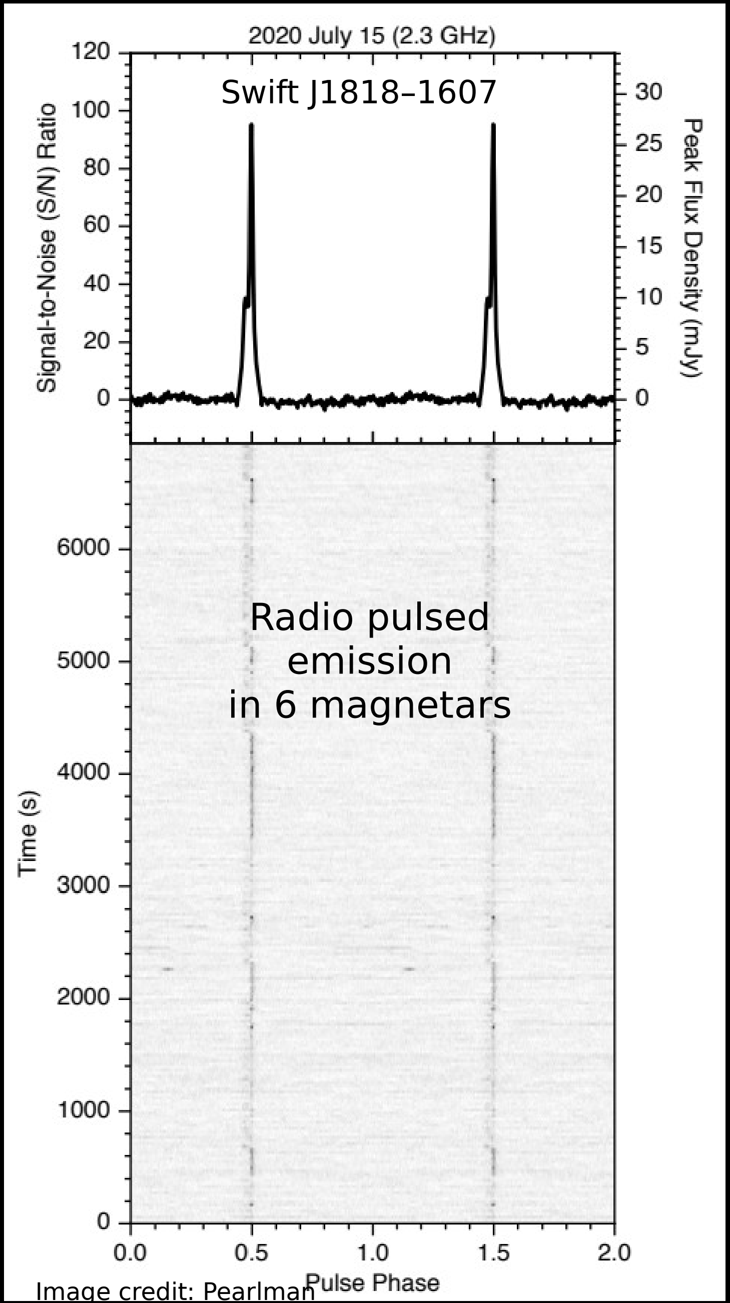
Data from ATNF catalogue v. 2.1.1

Magnetars: flaring activity

During an outburst



Rodriguez Castillo+ 2014



Radio pulsed emission
in 6 magnetars

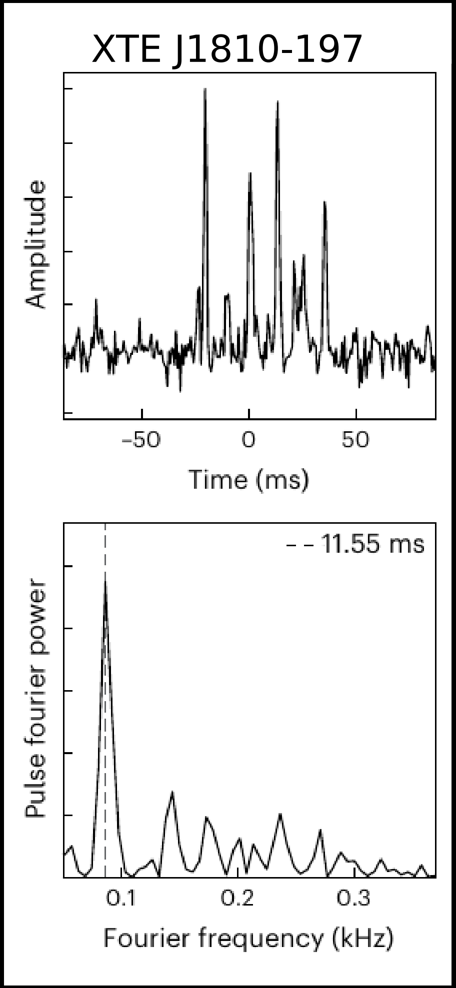
Image credit: Pearlman

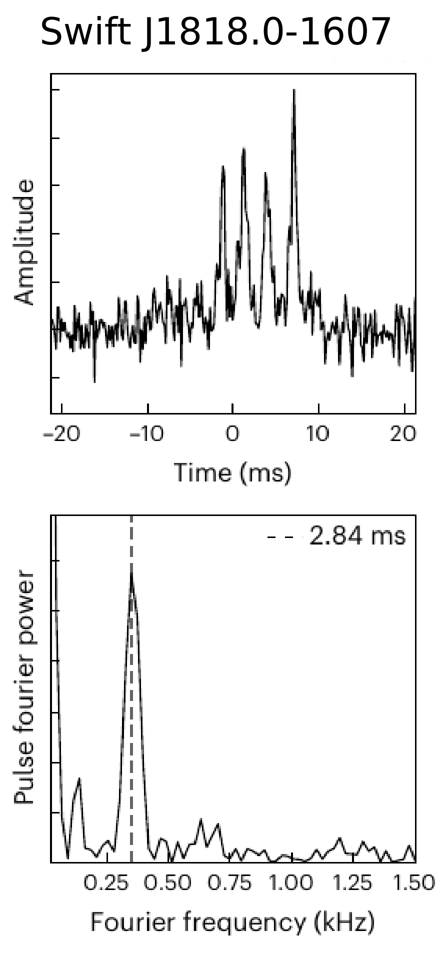
The spectrum of the radio-loud magnetars is flatter than that of RPPs

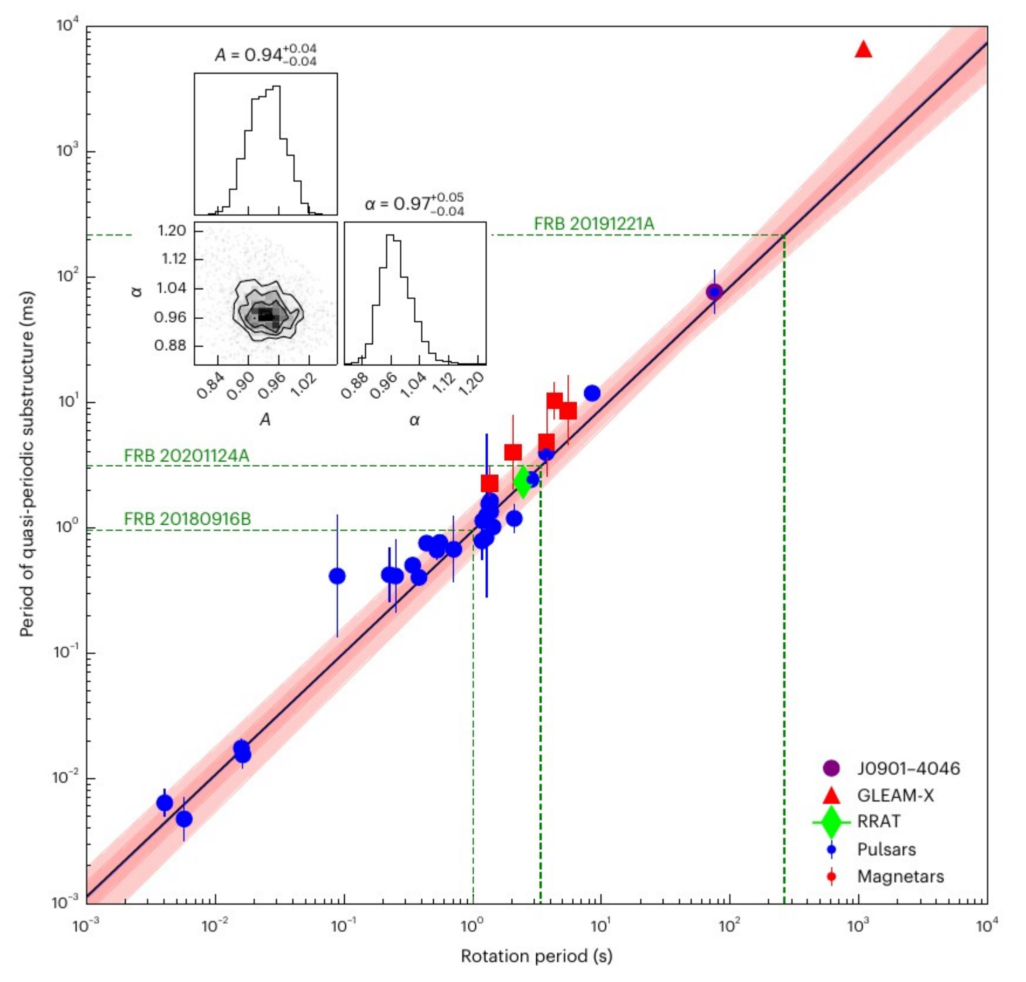
MAG: $S \propto \nu^{-0.5}$
RPPs: $S \propto \nu^{-1.8}$

Magnetars: radio emission

Quasi-periodic substructures as a unifying feature in the radio emission mechanisms of different neutron star classes


XTE J1810-197


Swift J1818.0-1607

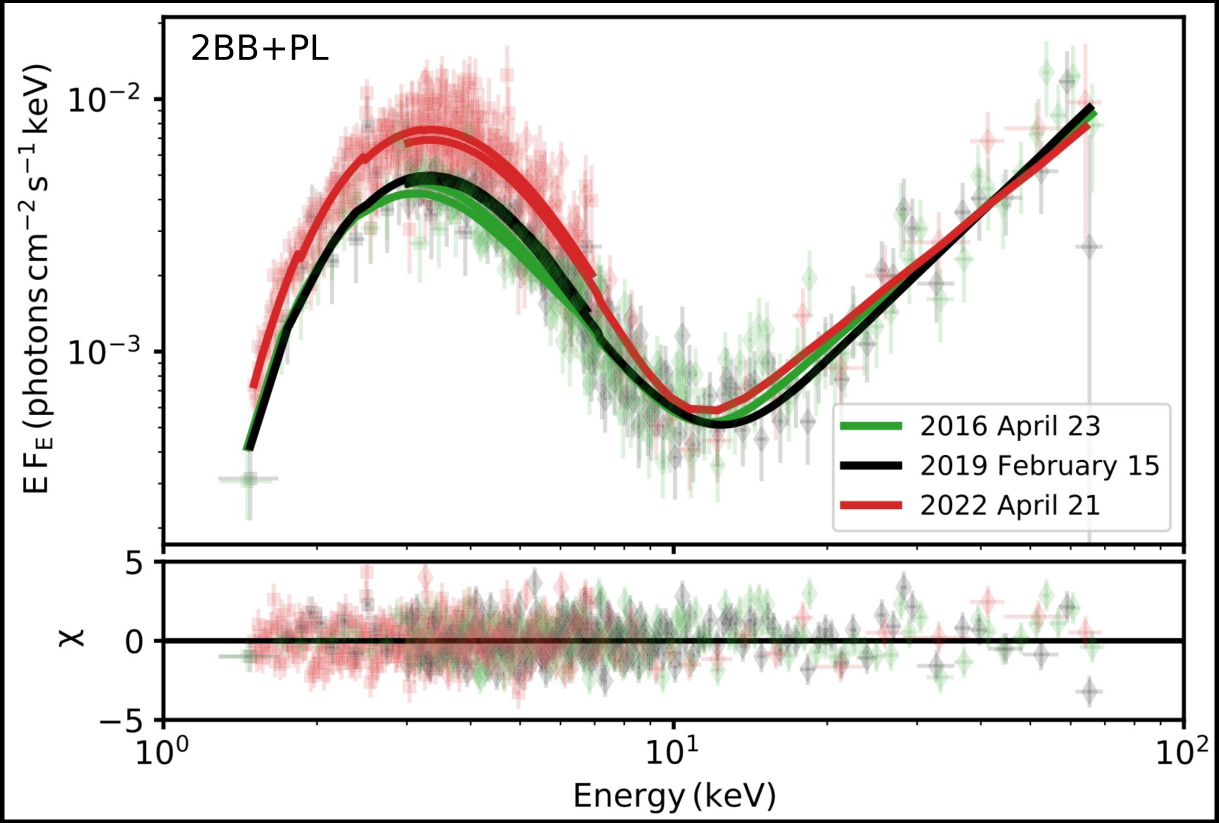


Kramer+ 2023

Magnetars: outbursts – a special case

1E 1547.0–5408

2022 April outburst



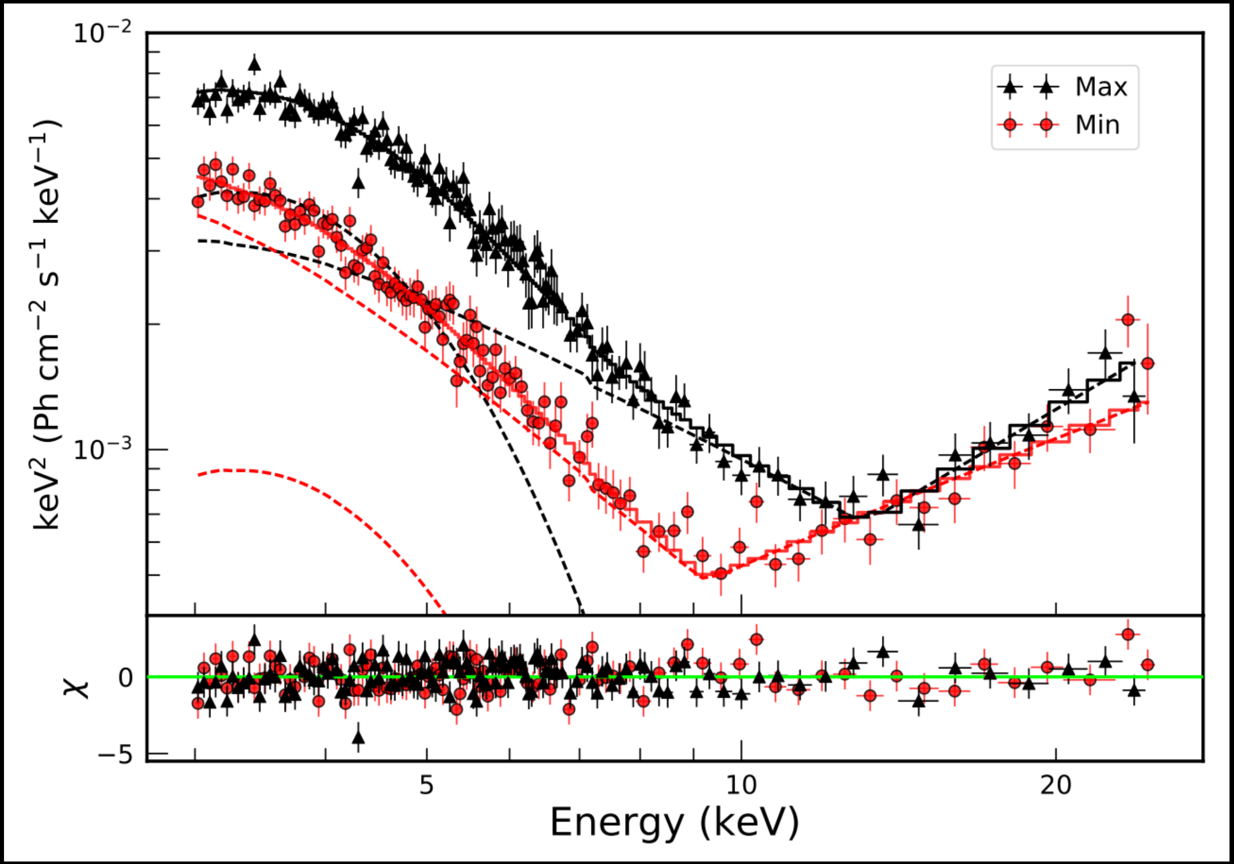
PL flux consistent between all 3 observations

2022 obs:
increase in the 0.5–10 keV flux due to an increase in the area of the $\mathrm{Bb}_{\mathrm{hot}}$ region
No changes in the *kTs* of the 2 Bbs and in the hardness of the PL

Lower+ 2023

Magnetars: outbursts – a special case

1E 1547.0–5408
Timing analysis and phase-resolved analysis on Feb 2019



MAX

E_{break} = 13.1 ± 0.6 keV

Γ_{soft} = 3.4 ± 0.1

Γ_{hard} = 0.5 ± 0.3

MIN

E_{break} = 9.2 ± 0.2 keV

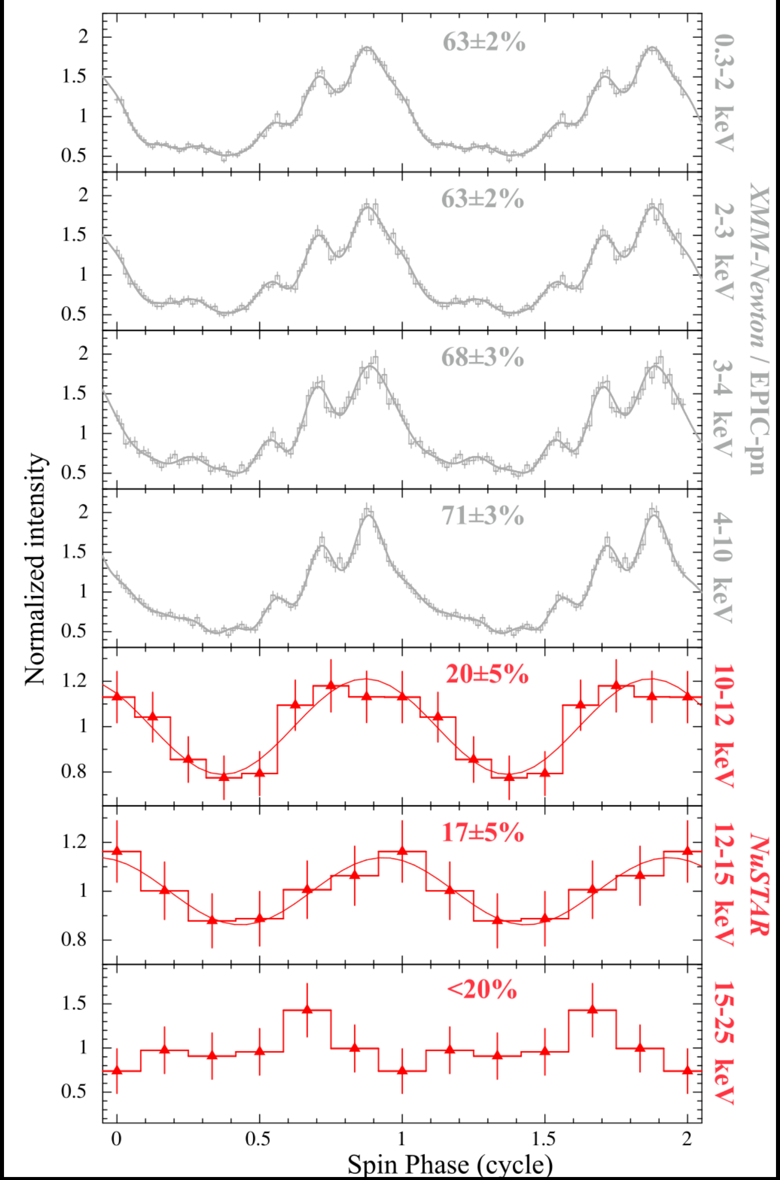
Γ_{soft} = 4.2 ± 0.1

Γ_{hard} = 1.0 ± 0.1

Coti Zelati, Borghese+ 2020

Magnetars: the latest additions

SGR 1830–0645
Discovered in outburst in October 2020



P ~ 10.42 s
Pdot ~ 7 x 10^{-12} s s^{-1}

$B_{dip,p}$ ~ 5.5 x 10^{14} G
Edot ~2.4 x 10^{32} erg s^{-1}
τ_c ~ 24 kyr

No radio periodic or single-pulse emission with the Sardinia Radio Telescope and Parkes.

Coti Zelati, Borghese+ 2021; see also Younes+ 2022a,b

Magnetars: the latest additions

Swift J1555.2–5402
Discovered in outburst in June 2021

$P \sim 3.86$ s
$\dot{P} \sim 3 \times 10^{-11}$ s s^{-1}

$B_{\mathrm{dip,p}} \sim 5.5 \times 10^{14}$ G
$\dot{E} \sim 2.4 \times 10^{32}$ erg s^{-1}
$\tau_c \sim 24$ kyr

No radio periodic or single-pulse emission with the Sardinia Radio Telescope and Parkes.

Enoto+ 2021

Magnetars: outbursts – a special case

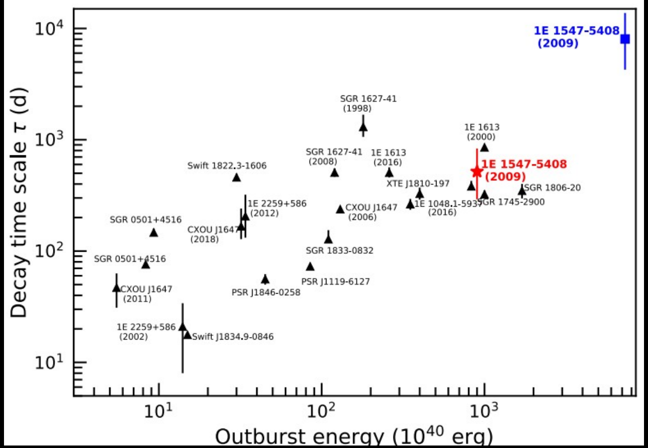
1E 1547.0–5408

A very slow luminosity decay?

Assuming that the luminosity decays back to the 2006 minimum level

$E_{\text{out}} \sim 7 \times 10^{43}$ erg decay time ~ 8000 d

”quiescence” in ~ 50 yr



Relaxing the assumption

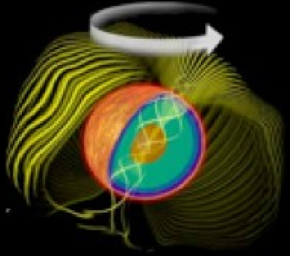
$E_{\text{out}} \sim 9 \times 10^{42}$ erg decay time ~ 500 d

$L_0 \sim 6 \times 10^{34}$ erg s^{-1}

How is it possible to retain a high level of luminosity for such a long time?

New persistent magnetospheric state with long-lived coronal currents (survival timescale of tens of years)

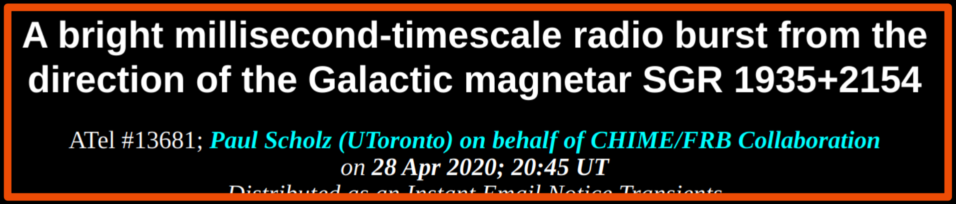
Currents are responsible for both thermal and non-thermal X-ray emission



Coti Zelati, Borghese+ 2020

Magnetars: recent highlights

The FRB-magnetar connection: SGR 1935+2154



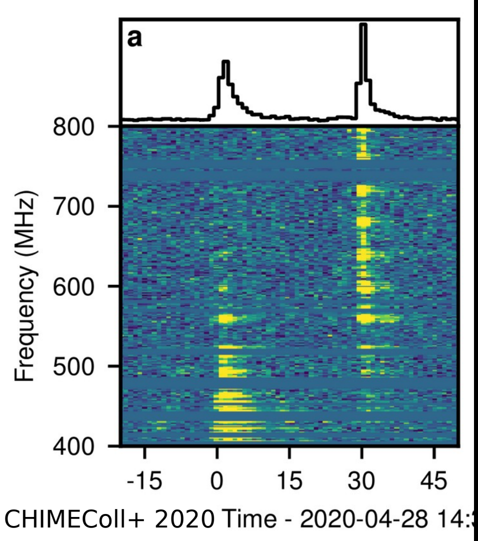
A bright millisecond-timescale radio burst from the direction of the Galactic magnetar SGR 1935+2154

ATel #13681; *Paul Scholz (UToronto) on behalf of CHIME/FRB Collaboration*
on ***28 Apr 2020; 20:45 UT***
Distributed as an Instant Email Notice Transients

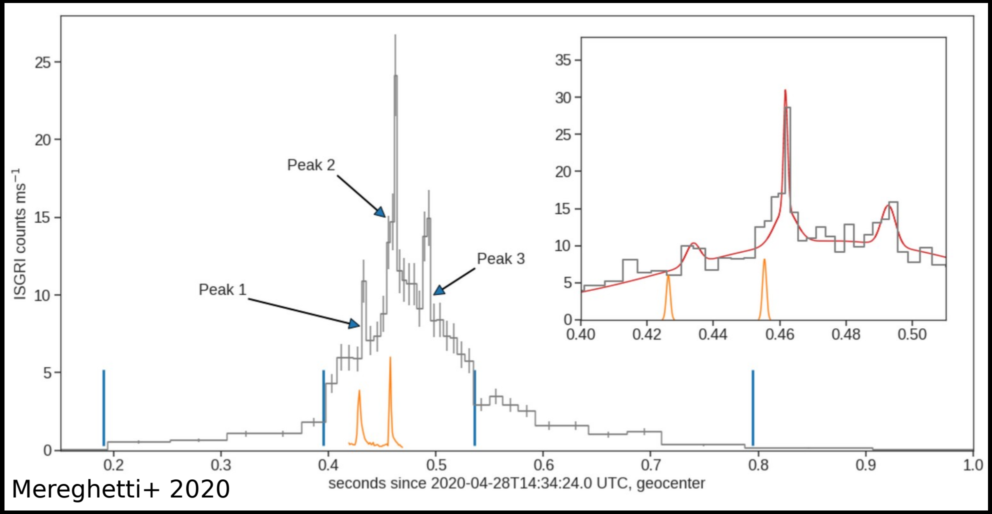
INTEGRAL IBIS and SPI-ACS detection of a hard X-ray counterpart of the radio burst from SGR 1935+2154

ATel #13685; *S. Mereghetti (INAF, IASF-Milano), V. Savchenko (ISDC, Versoix), D. Gotz, J. Rodriguez (CEA, Saclay), L. Ducci, C. Ferrigno, E. Bozzo (ISDC, Versoix), J. Borkowski (CAMK, Torun) and A. Bazzano (INAF, IAPS-Roma)*
on ***29 Apr 2020; 10:53 UT***

CHIME
400-800 MHz



Integral
20–200 keV



Two pulses separated by ~30 ms

Fluence 480 kJy ms + 220 kJy ms

Energy$_{\text{radio,iso}}$ ~ 10$^{34\text{-}35}$ erg

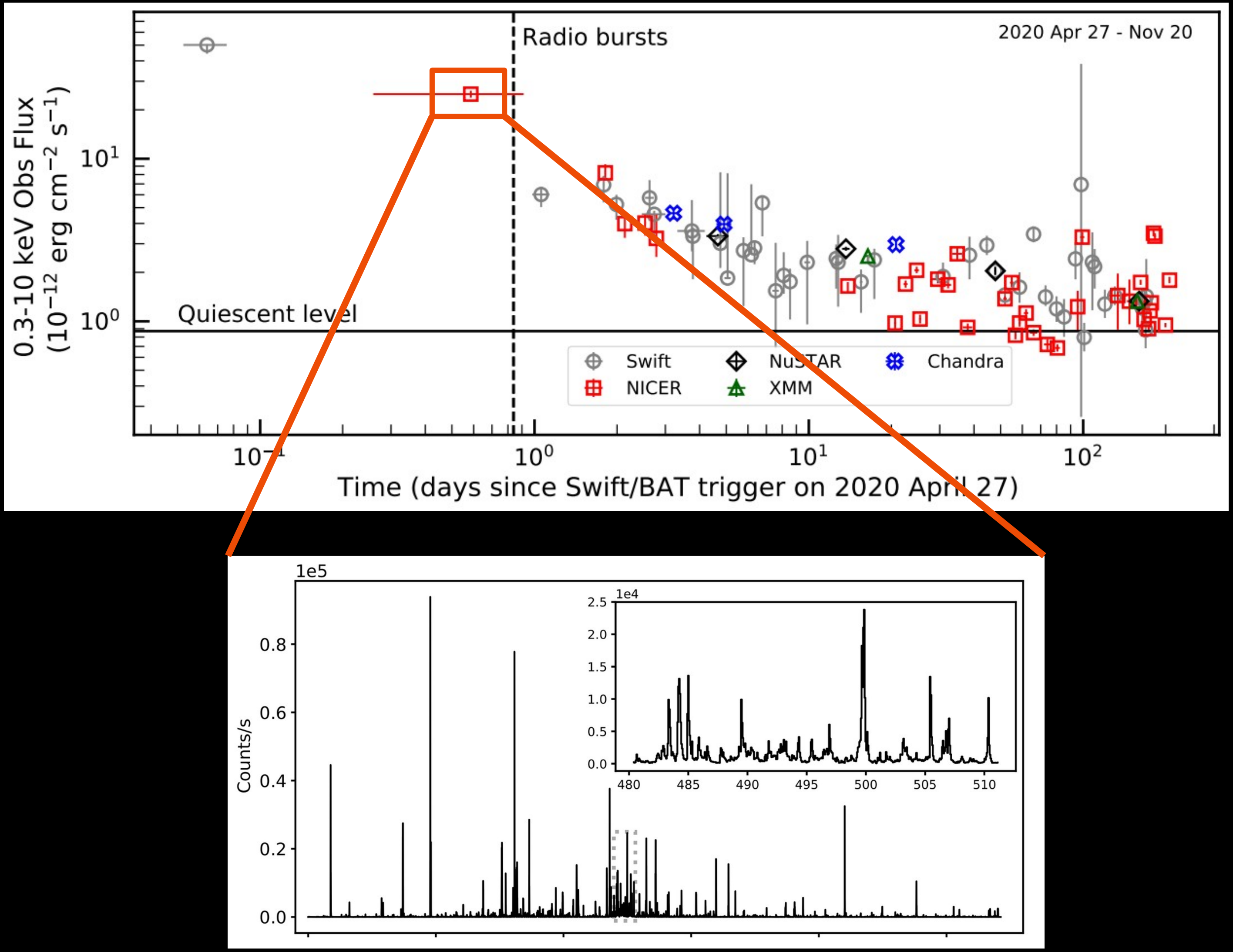
Main pulse (~0.15 s) with three narrow peaks, separated by ~30 ms

Harder spectrum than those of typical bursts

Energy$_{\text{X,iso}}$ ~ 1.5 x 10^{39} erg (at 4.4 kpc)

Andersen+ 2020; Bochenek+ 2020; Mereghetti+ 2020; Li+ 2021; Ridnaia+ 2021; Tavani+ 2021

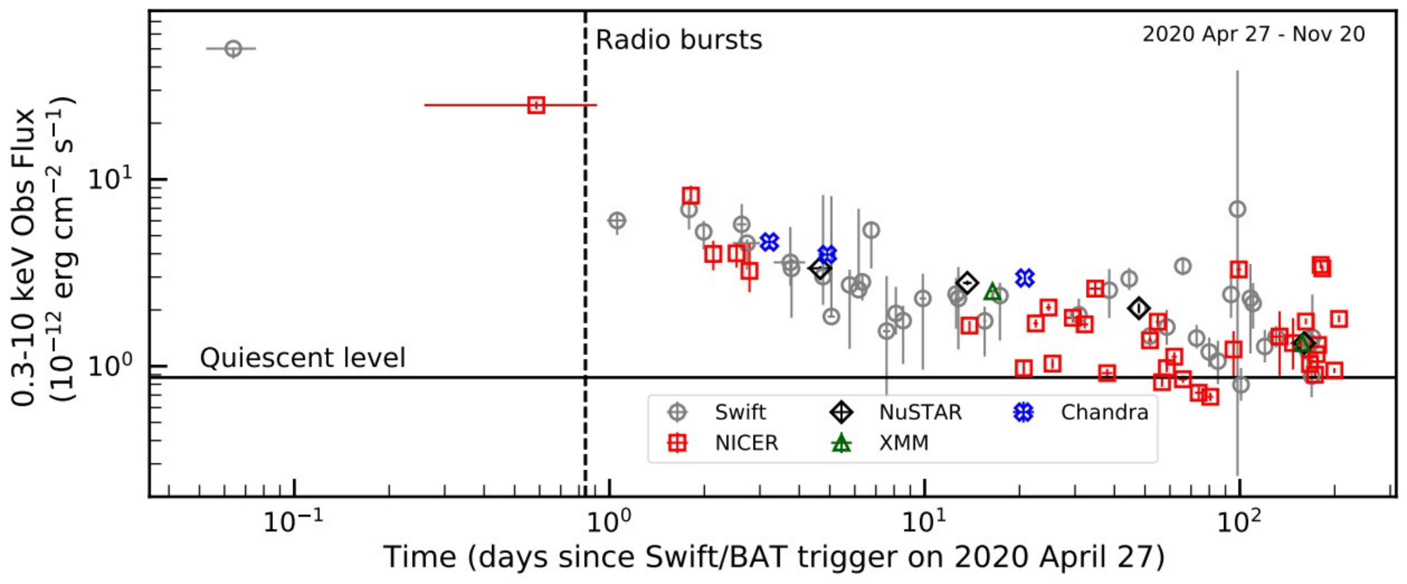
The FRB-magnetar connection: SGR 1935+2154
during an X-ray outburst



NICER detected 217 bursts in about 1100 seconds, six hours after the *Swift*/BAT trigger

Borghese+ 2020, 2022; Younes+ 2020

The FRB-magnetar connection: SGR 1935+2154
during an X-ray outburst



The source reached quiecence ~80d after the onset, releasing an energy of ~6 x 10^{40} erg

This outburst is similar to the other outbursts emitted by the same source and any other magnetars

We might have missed previous radio bursts because of the lack of sensitive radio antenna

Borghese+ 2020, 2022; Younes+ 2020

The FRB-magnetar connection: SGR 1935+2154

More simultaneous X-ray and radio bursts in Oct and Dec 2022

CHIME/FRB Detection of a Bright Radio Burst from SGR 1935+2154

ATel #15681; ***Fengqiu Adam Dong (University of British Columbia), on behalf of the CHIME/FRB Collaboration***

on **15 Oct 2022; 03:09 UT**

Konus-Wind detection of a short X-ray burst coincident with a bright radio burst from SGR 1935+2154

ATel #15686; ***D. Frederiks, A. Ridnaia, D. Svinkin, A. Lysenko, M. Ulanov (all - Ioffe Institute), and A. Tsvetkova (Ioffe Institute/University of Cagliari)***

on **16 Oct 2022; 15:51 UT**

CHIME/FRB Detection of Another Bright Radio Burst from SGR 1935+2154

ATel #15792; ***Aaron B. Pearlman (McGill University; Trottier Space Institute at McGill University) on behalf of the CHIME/FRB Collaboration***

on **5 Dec 2022; 20:18 UT**

GBM detection of a faint magnetar-like burst temporally coincident with a CHIME/FRB radio burst

ATel #15794; ***G. Younes (NASA GSFC), E. Burns (LSU), O. J. Roberts (USRA), J. Wood (NASA/MSFC), P. Veres (UAH), C. Kouveliotou (GWU) On behalf of a larger collaboration***

on **6 Dec 2022; 16:24 UT**

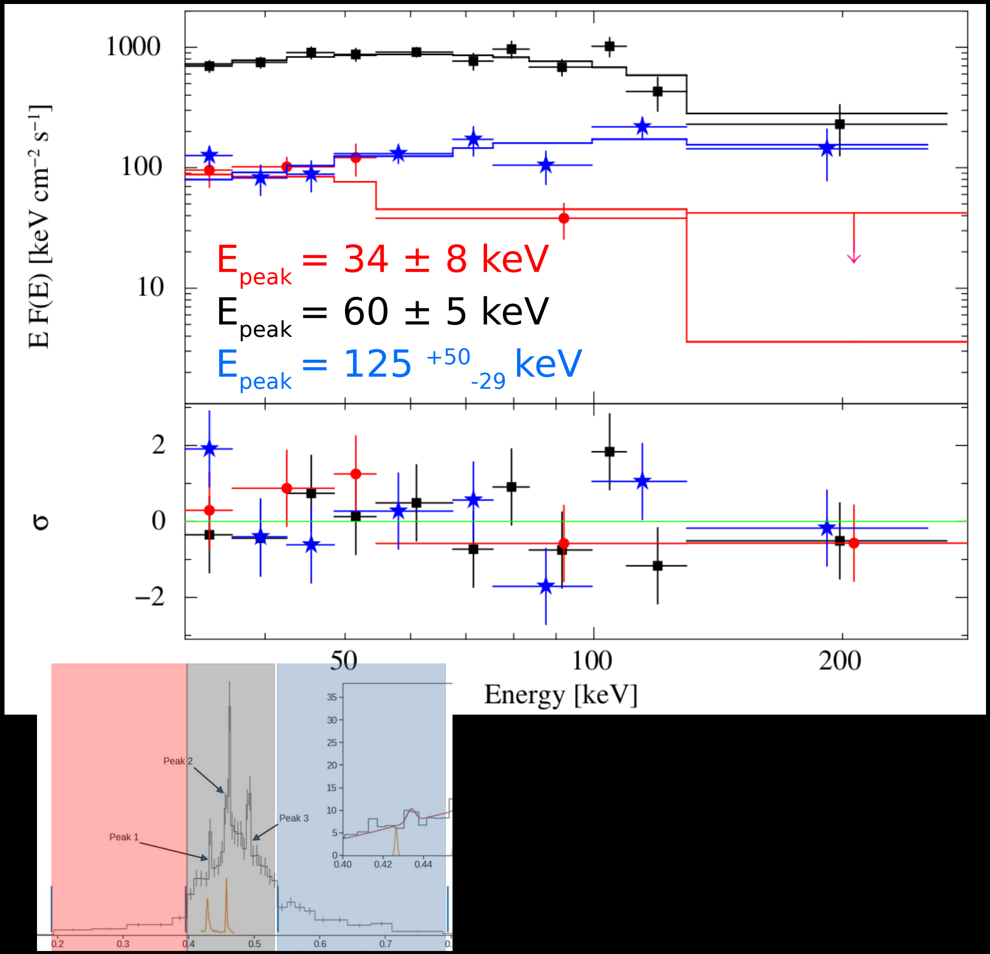
To find out more about the 2022 re-activation

Abu Ibrahim's talk

Magnetars: the radio bursting magnetar – SGR J1935+2154

2020 April 27–28: reactivation with X-ray burst forest and FRB-like radio burst

Hard X-ray burst associated with the FRB-like radio burst

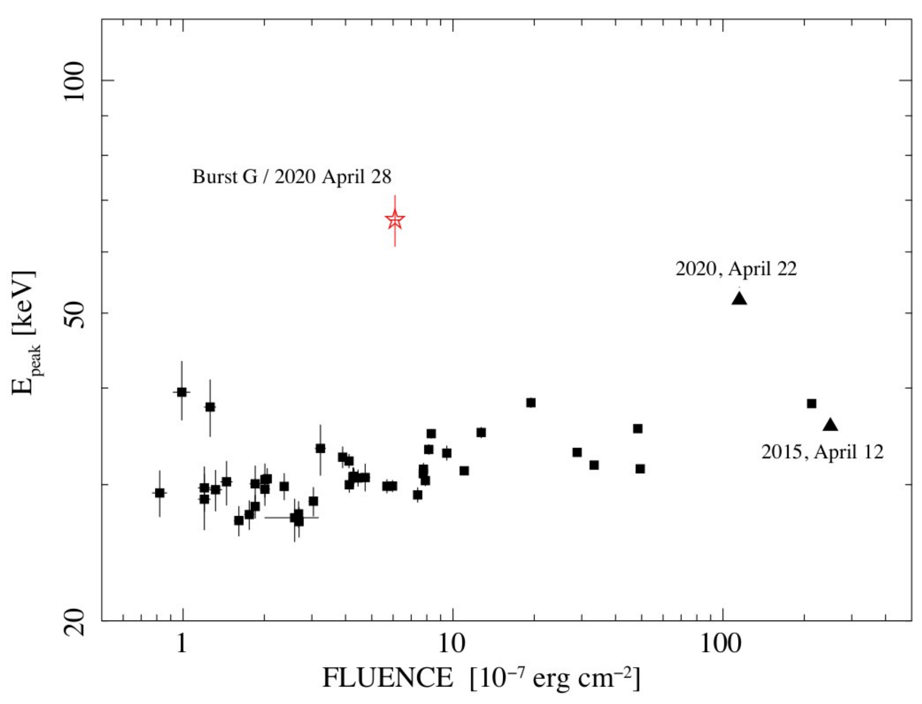


E_{peak} = 34 ± 8 keV

E_{peak} = 60 ± 5 keV

$E_{peak} = 125^{+50}_{-29}$ keV

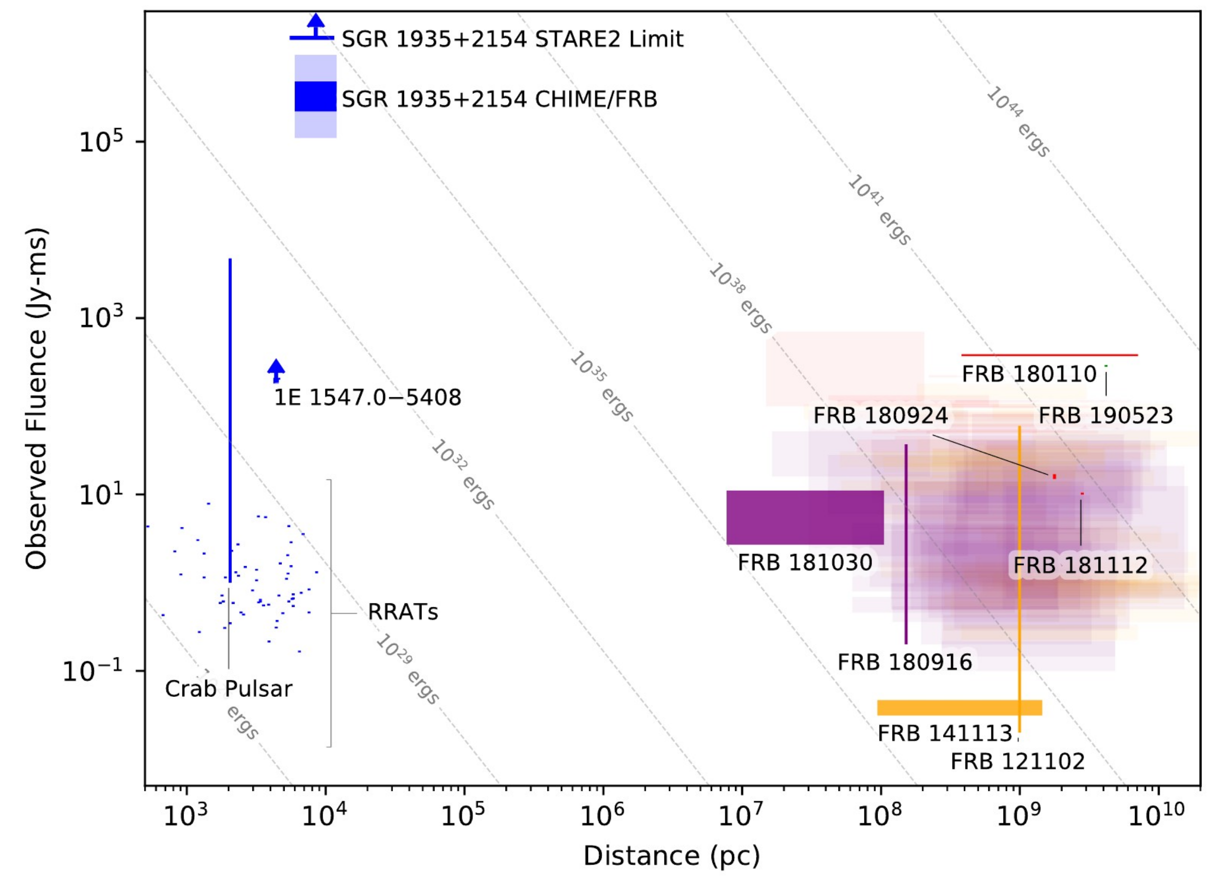
Fluence (20-200 keV) ~ 6 x 10^{-7} erg cm^{-2}



Mereghetti+ 2020

Magnetars: the radio bursting magnetar – SGR J1935+2154

2020 April 28: FRB-like radio burst



Energy$_{\text{radio}}$ ~ $10^{34\text{-}35}$ erg

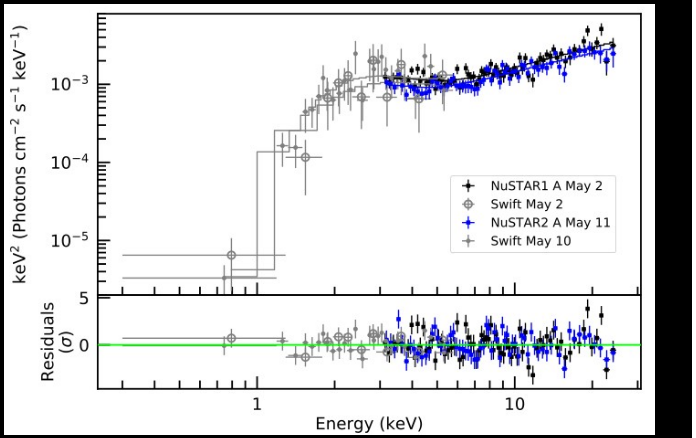
~ x 1000 higher than the most energetic GALACTIC pulses

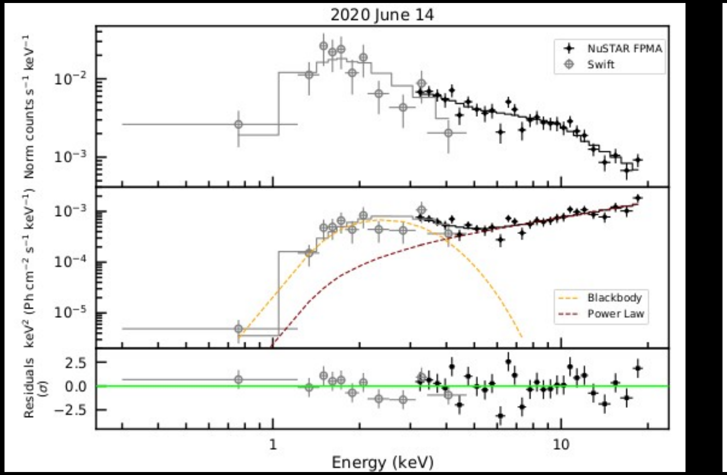
~ x 40 lower than the least energetic FAST RADIO BURST

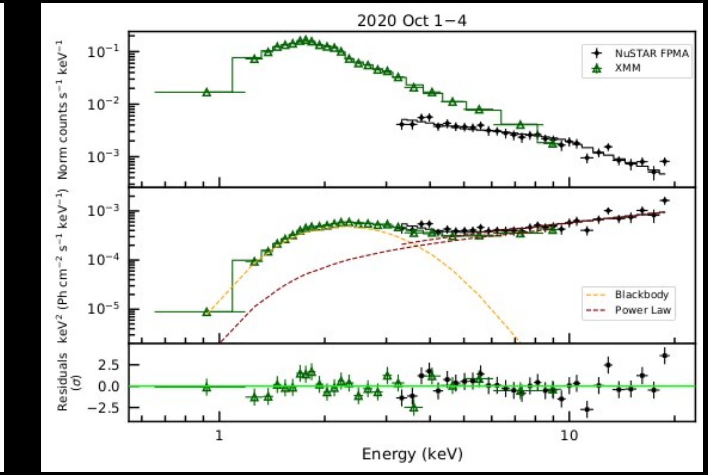
Magnetar radio bursts a bridge between extragalactic FRBs and Galactic radio pulsar bursts

Magnetars: the radio bursting magnetar – SGR J1935+2154

X-ray monitoring campaign of the 2020 April outburst from 2020 Apr till Nov

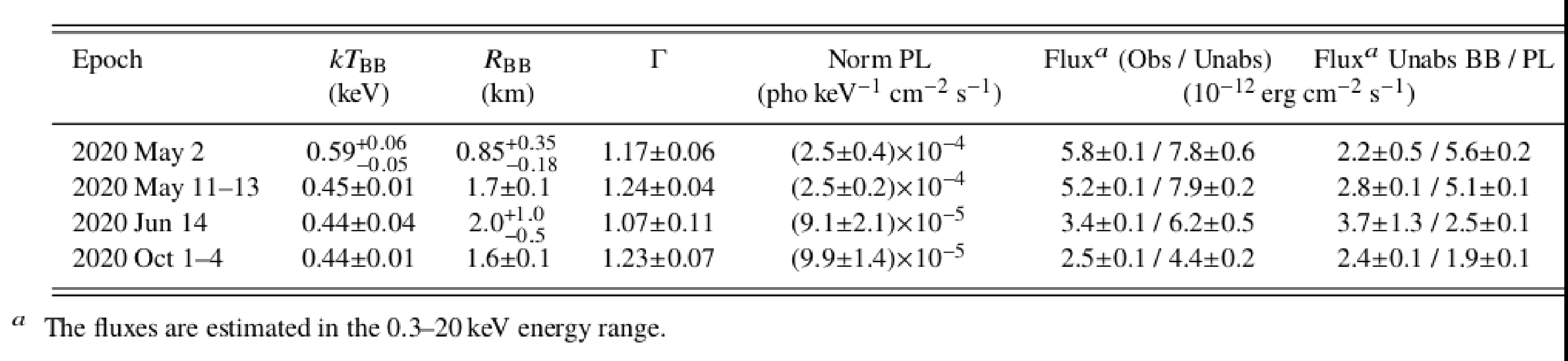






emission up till ~25 keV

emission up till ~20 keV

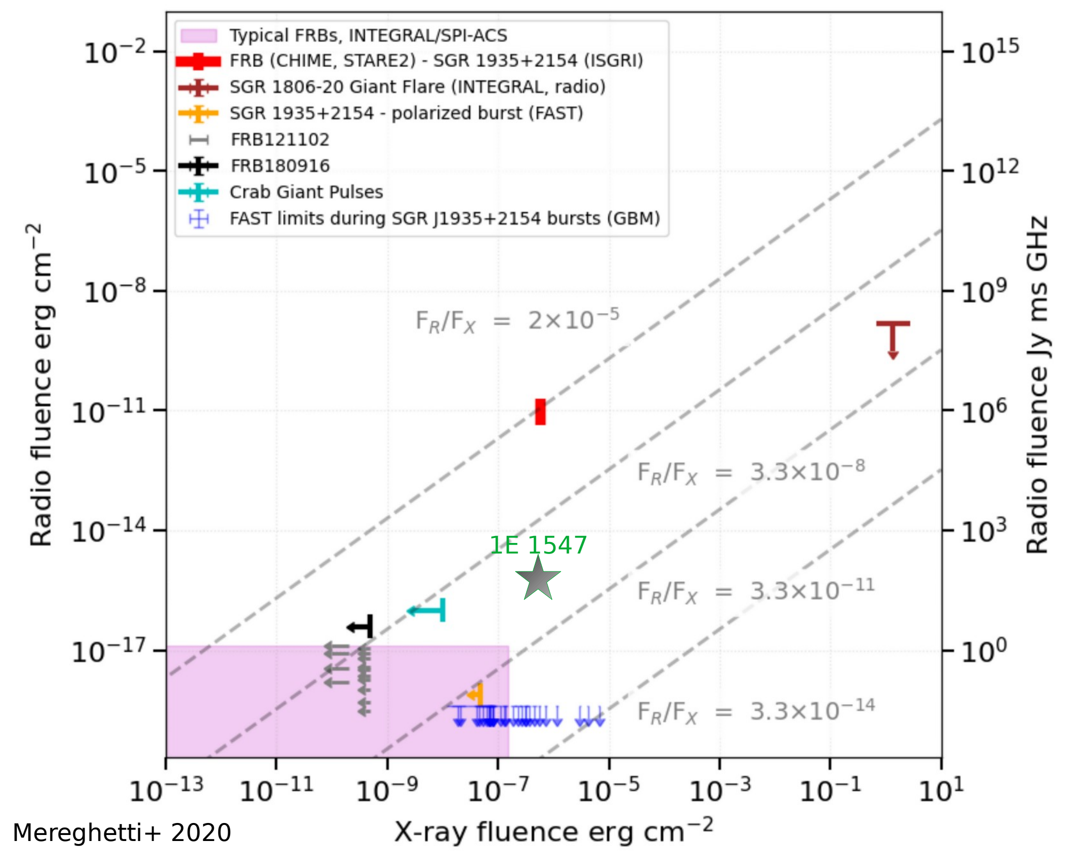


Epoch	kT_{BB} (keV)	R_{BB} (km)	Γ	Norm PL (pho keV^{-1} cm^{-2} s^{-1})	Flux[a] (Obs / Unabs) (10^{-12} erg cm^{-2} s^{-1})	Flux[a] Unabs BB / PL (10^{-12} erg cm^{-2} s^{-1})
2020 May 2	$0.59^{+0.06}_{-0.05}$	$0.85^{+0.35}_{-0.18}$	1.17±0.06	$(2.5\pm0.4)\times10^{-4}$	5.8±0.1 / 7.8±0.6	2.2±0.5 / 5.6±0.2
2020 May 11–13	0.45±0.01	1.7±0.1	1.24±0.04	$(2.5\pm0.2)\times10^{-4}$	5.2±0.1 / 7.9±0.2	2.8±0.1 / 5.1±0.1
2020 Jun 14	0.44±0.04	$2.0^{+1.0}_{-0.5}$	1.07±0.11	$(9.1\pm2.1)\times10^{-5}$	3.4±0.1 / 6.2±0.5	3.7±1.3 / 2.5±0.1
2020 Oct 1–4	0.44±0.01	1.6±0.1	1.23±0.07	$(9.9\pm1.4)\times10^{-5}$	2.5±0.1 / 4.4±0.2	2.4±0.1 / 1.9±0.1

[a] The fluxes are estimated in the 0.3–20 keV energy range.

Borghese+ 2020; Borghese+ 2022

The FRB-magnetar connection



Mereghetti+ 2020

SGR 1935, 2020 April 28
$F_R/F_x \sim 2 \times 10^{-5}$

SGR 1935, 2020 April 30
$F_R/F_x \gtrsim 3 \times 10^{-11}$

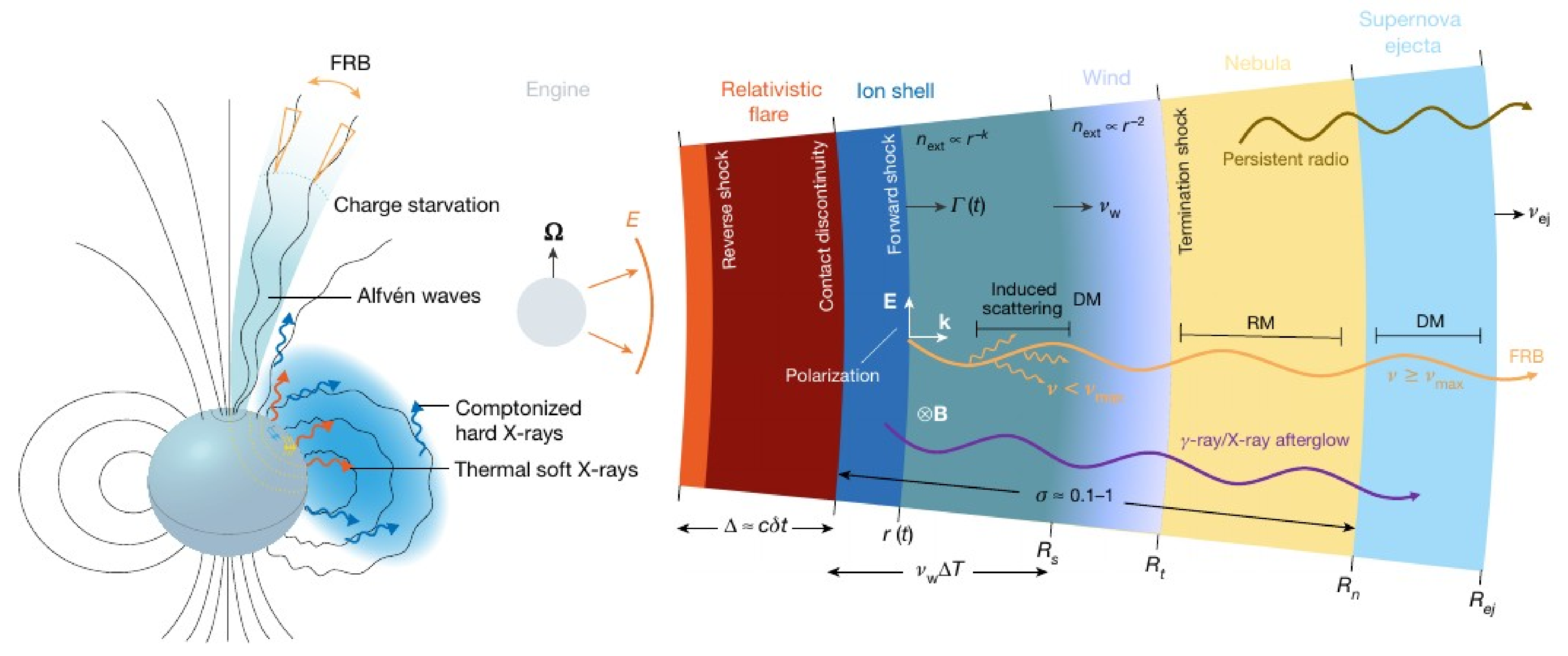
SGR 1806, 2004 Giant Flare
$F_R/F_x \lesssim 10^{-9}$

1E 1547, 2009 Feb 3
$F_R/F_x \sim 10^{-9}$

The FRB-magnetar connection

Pulsar-like

GRB-like



Emission inside the magnetosphere

Emission in relativistic outflow interacting with the surrounding medium

Zhang B. 2020

Central Compact Objects

Point-like sources close to the center of supernova remnants

No counterparts at other wavelenghts

Thermal-like spectrum
$L_X \sim$ few 10^{33} erg s^{-1}

1E 1207.4 – 5209

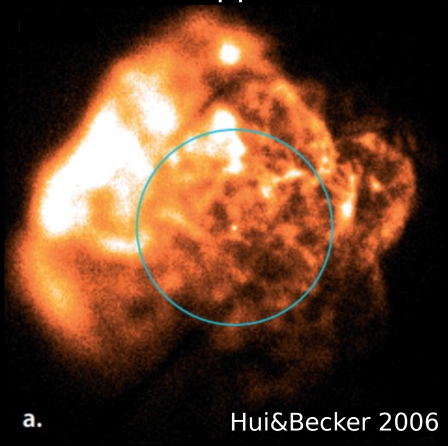
SNR PKS 1209-51/52

De Luca+ 2004

P ~ 0.4 s
Pdot~2 x 10^{-17} s s^{-1}
$B_{dip} \sim 9 \times 10^{10}$ G

RX J0822.0 – 4300

Puppis A



Hui&Becker 2006

P ~ 0.1 s
Pdot~9 x 10^{-18} s s^{-1}
$B_{dip} \sim 3 \times 10^{10}$ G

CXOU J185238+0040

Kes 79

Auchettl+ 2018

P ~ 0.1 s
Pdot~9 x 10^{-18} s s^{-1}
$B_{dip} \sim 3 \times 10^{10}$ G

Anti-magnetar scenario versus hidden-magnetic field scenario

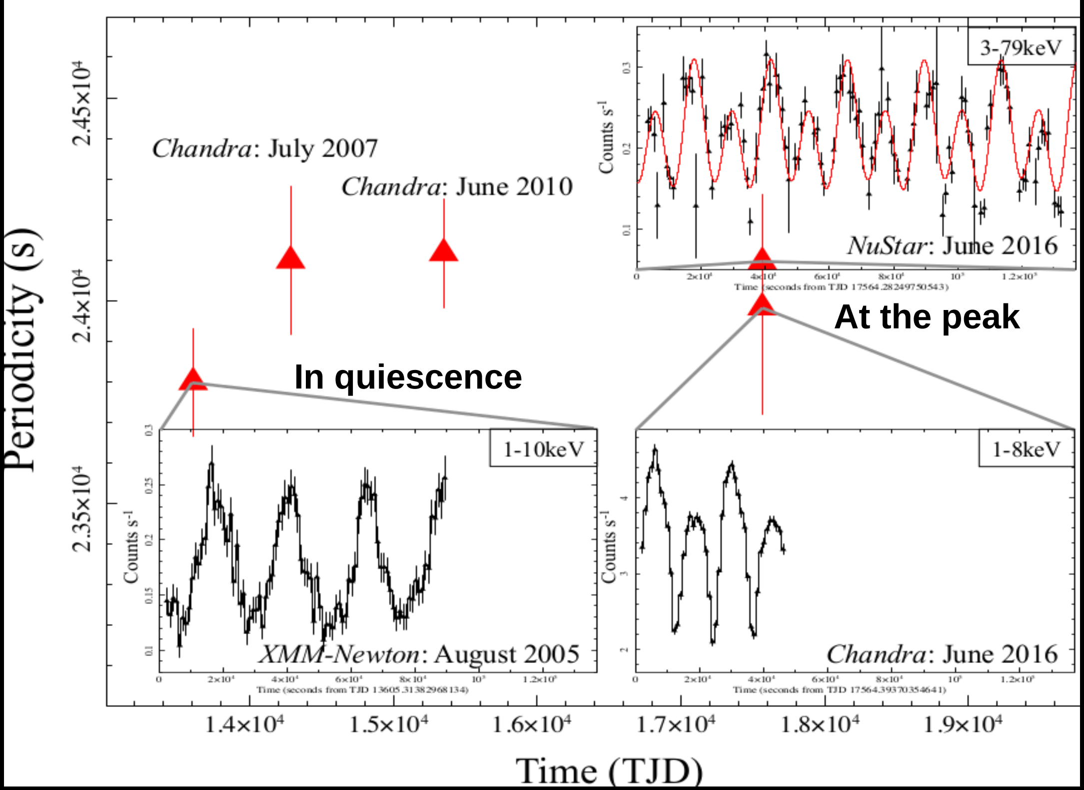
Halpern & Gotthelf 2009, 2010, 2011; Gotthelf+ 2013; Shabaltas & Lai 2012; Viganò & Pons 2012; Torres-Forné + 2016; Igoshev+ 2016

Magnetar-like activity from non-canonical magnetars

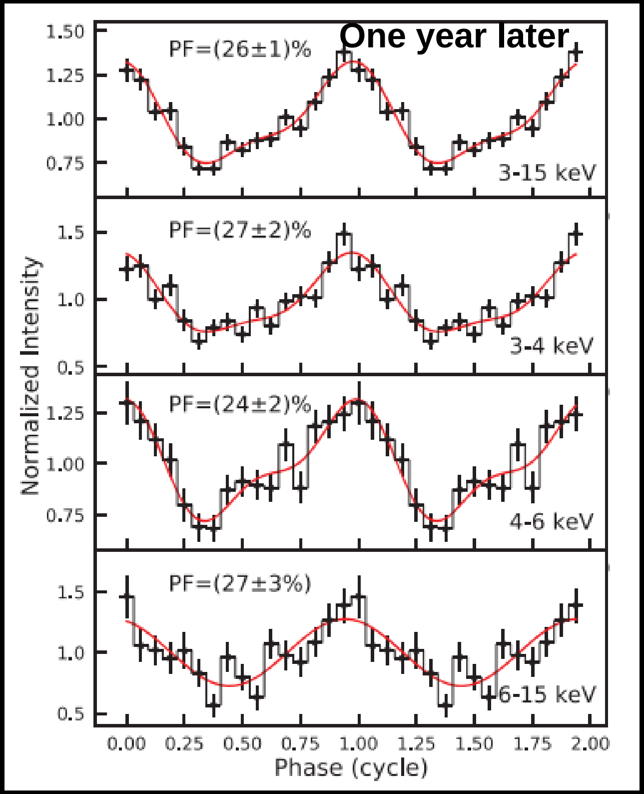
CENTRAL COMPACT OBJECTS

1E 161348-5055

at the center of the SNR RCW103 with $P \sim 6.67$ h and age ~ 2ky


In quiescence

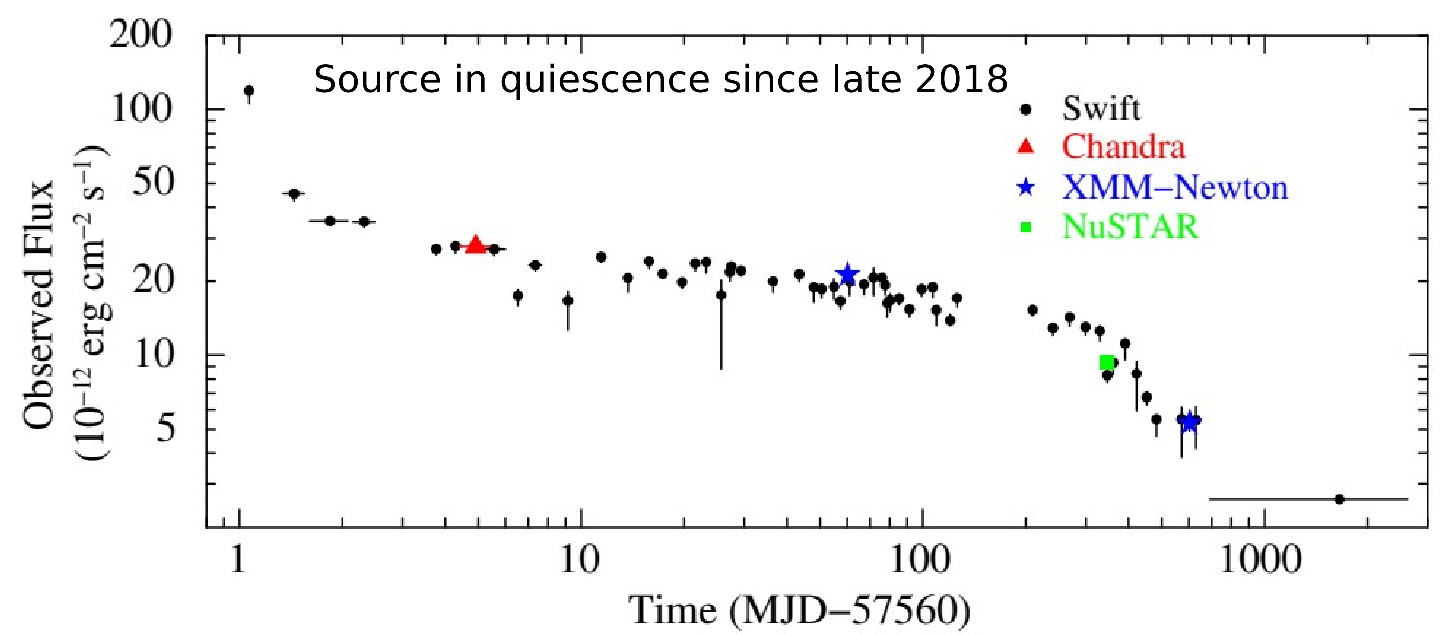
At the peak


One year later

Rea, Borghese+ 2016; D’Ai’+ 2018; Borghese+ 2018

Central Compact Object: RCW 103

Long-term monitoring with Swift
Since the 2016 outburst onset till 2023 Sep


Source in quiescence since late 2018

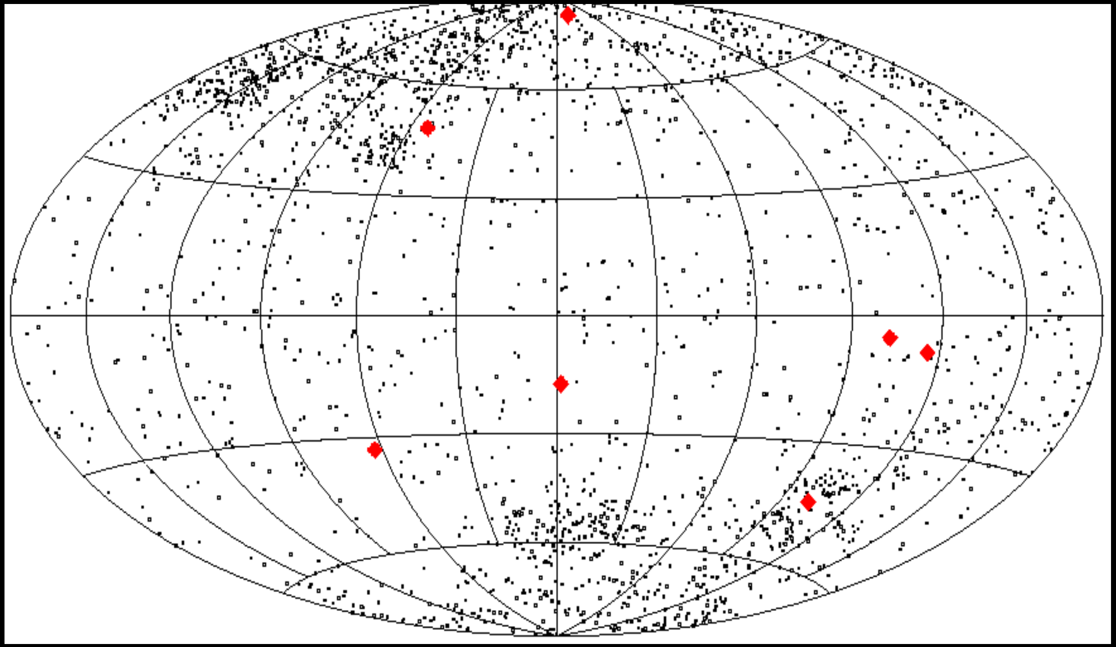
A hidden magnetar… but a very **slow** magnetar with a period of **6.67 hr**

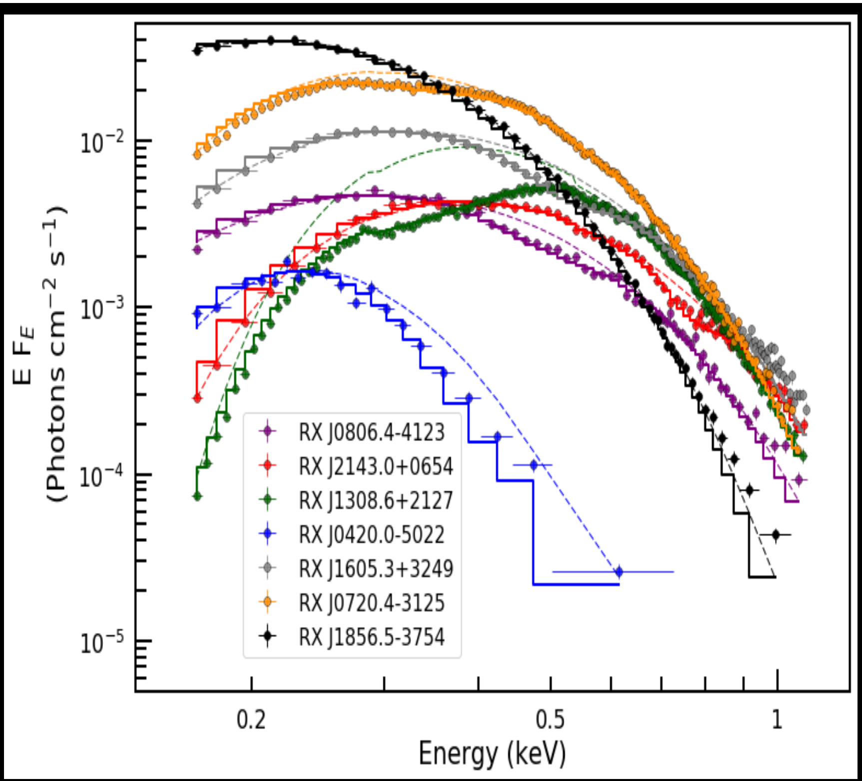
How to slow down a NS to P~6.67 hr in ~ **2 kyr**?

An external torque is required:

propeller interaction in an early phase of the fall-back accretion

X-ray Dim Isolated Neutron Stars





Distance: d $\lesssim$ 500 pc

Spin period: P ~ 3 – 11 s

Magnetic field: $B_{dip} \approx 10^{13}$ G

Age: $\tau \approx 10^6$ yr

Luminosity $L_x \approx 10^{31\text{-}32}$ erg s^{-1}

No radio emission

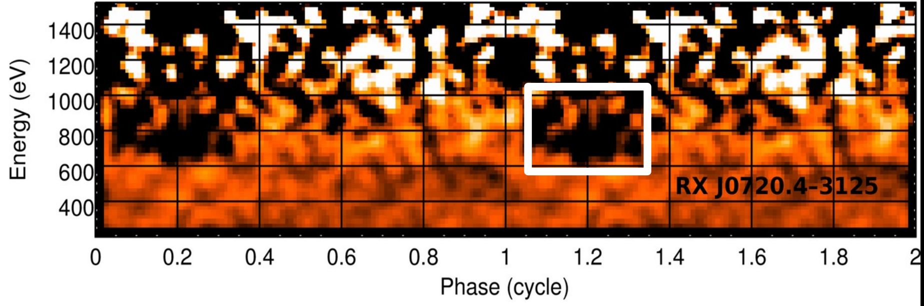
Thermal X-ray spectra
kT_{BB} ~ 50-100 eV

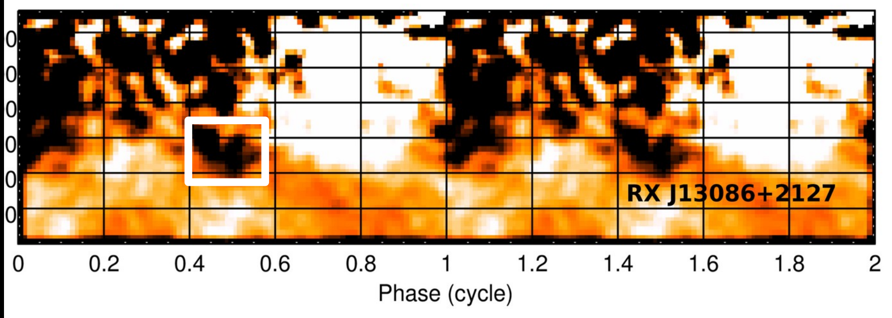
plus a broad absorption feature
E_{line} ~ 0.2-0.8 keV

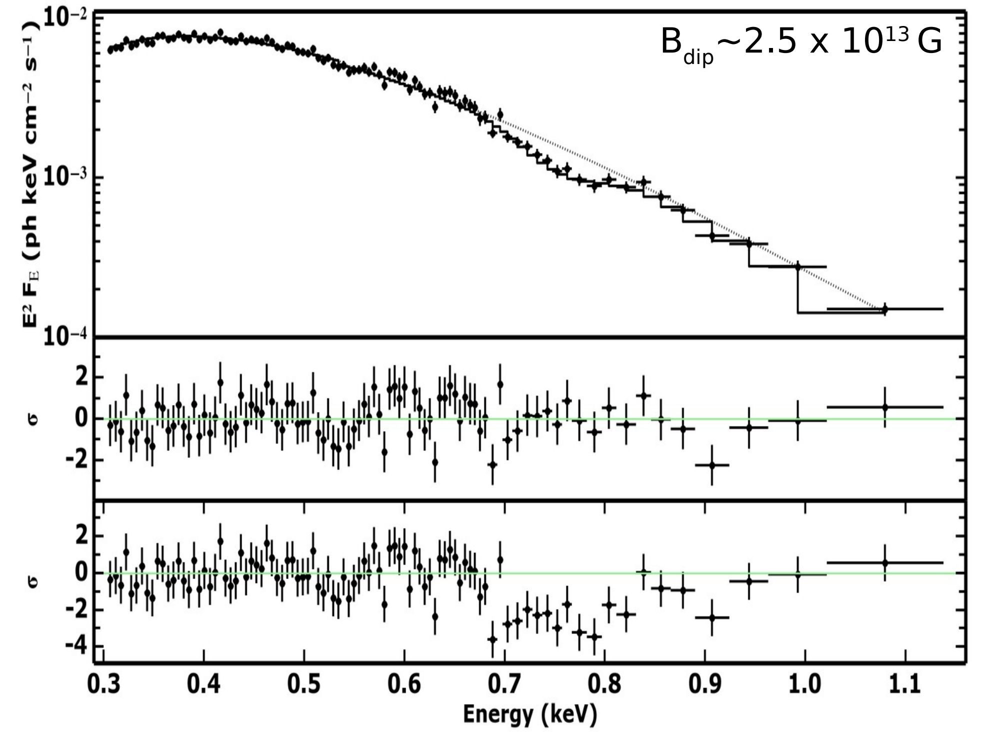
For reviews van Kerkwijk & Kaplan 2007; Turolla 2009

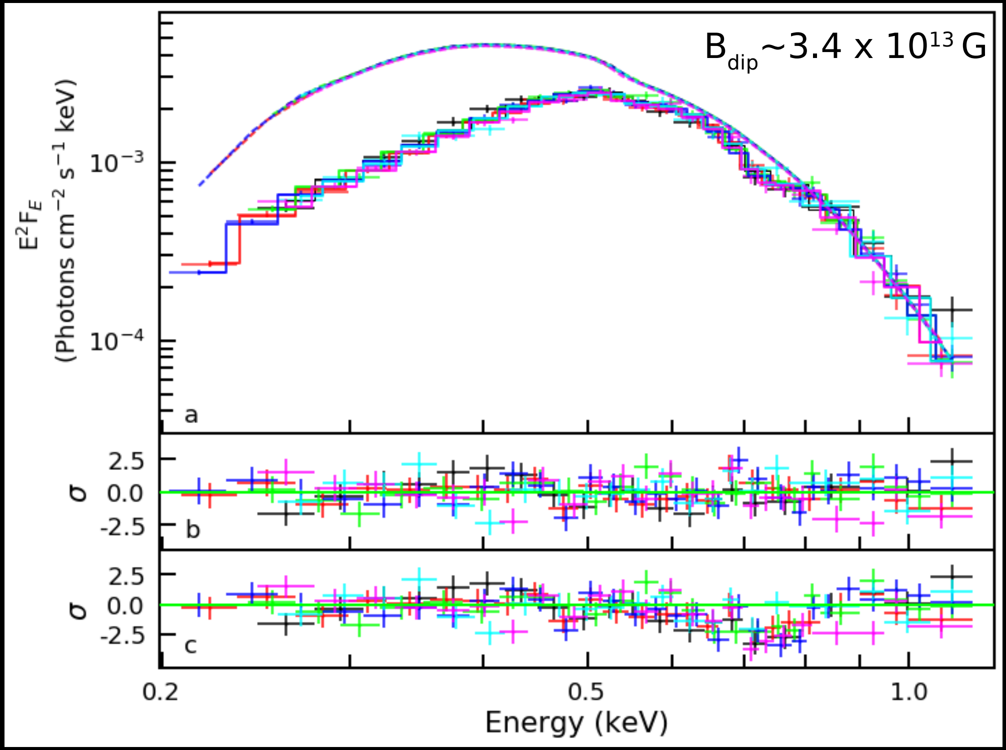
X-ray Dim Isolated Neutron Stars: as old magnetars

Narrow phase-dependent absorption features





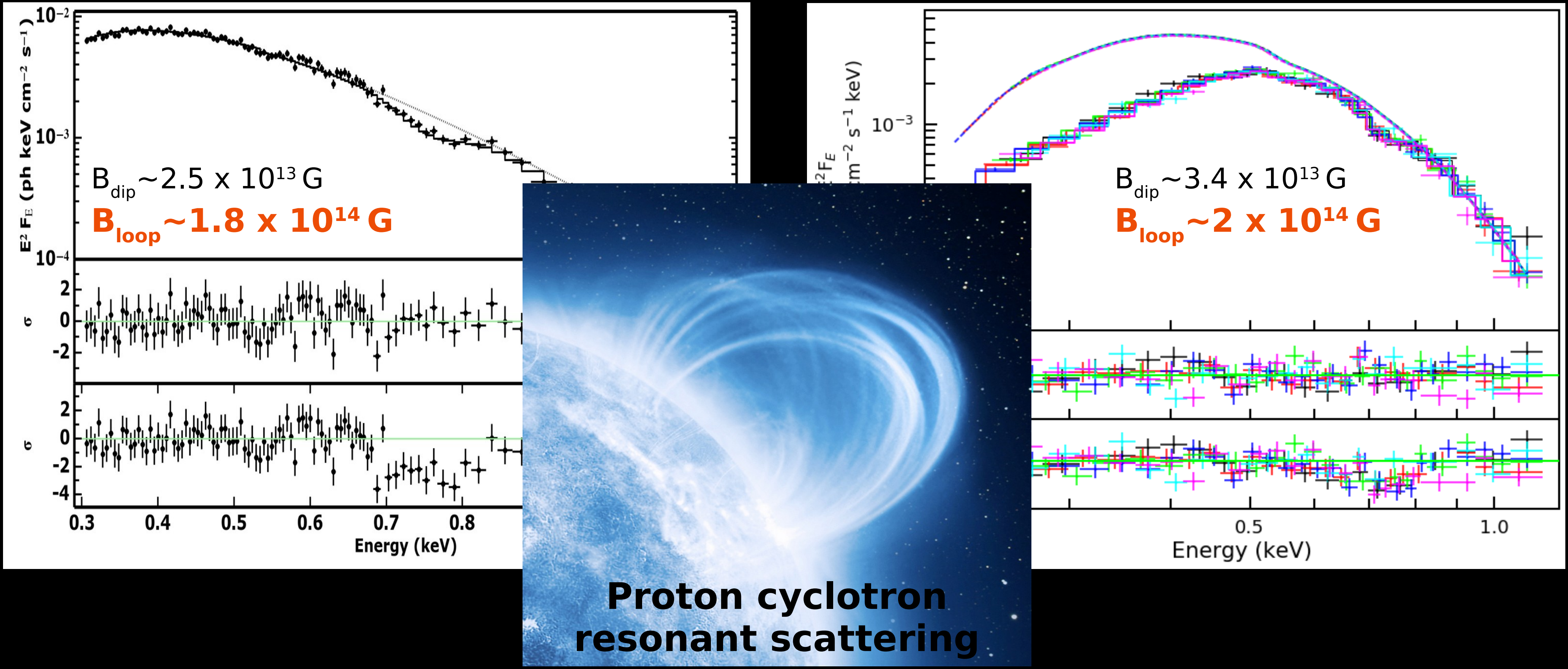

B_{dip}~2.5 x 10^{13} G


B_{dip}~3.4 x 10^{13} G

Borghese+ 2015, 2017

X-ray Dim Isolated Neutron Stars: as old magnetars

Narrow phase-dependent absorption features



B_{dip}~2.5 x 10^{13} G

B_{loop}~1.8 x 10^{14} G

B_{dip}~3.4 x 10^{13} G

B_{loop}~2 x 10^{14} G

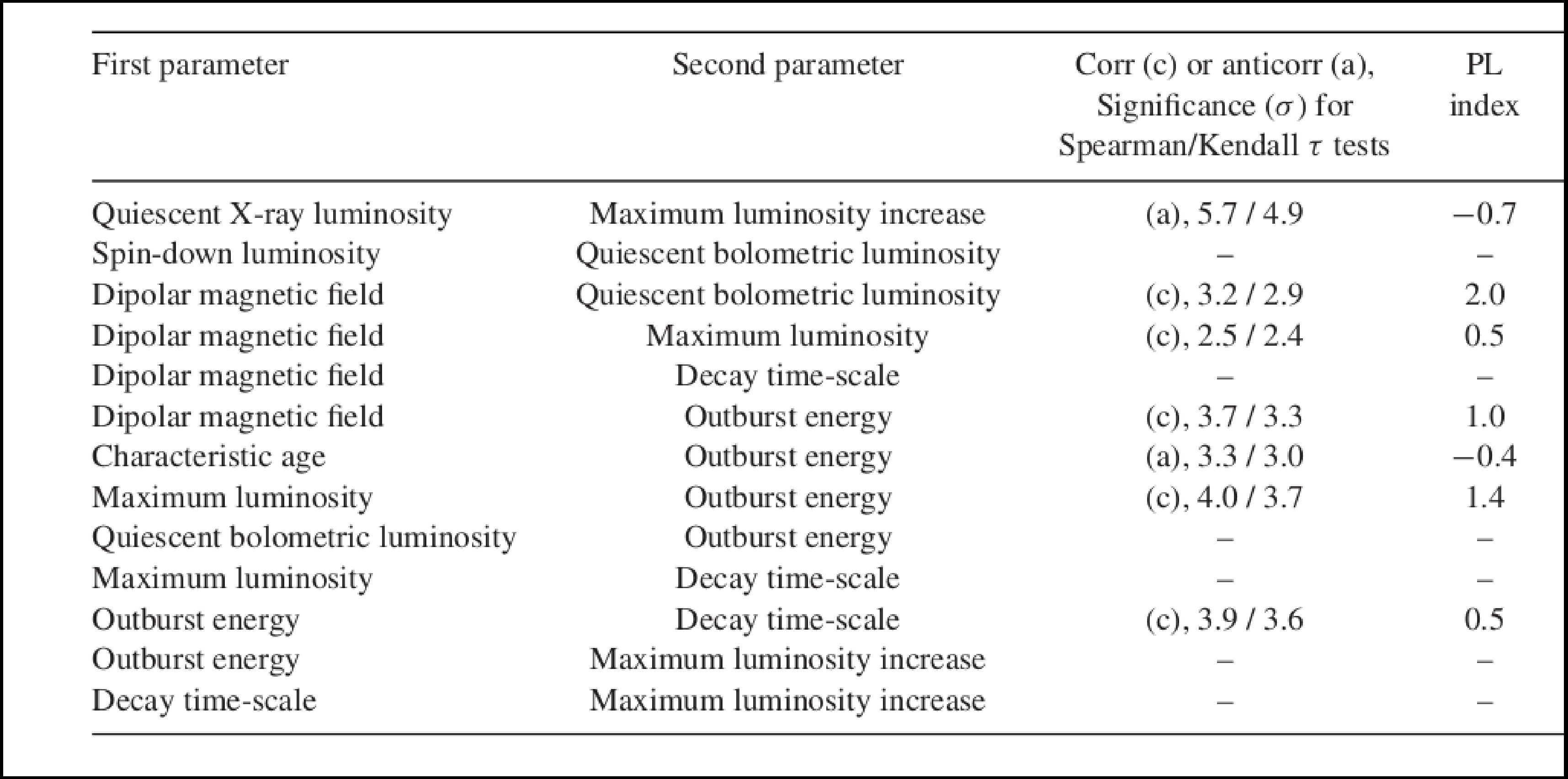
Proton cyclotron resonant scattering

First observational evidence for a complex magnetic field in the XDINSs

Evolutionary connection between XDINSs and magnetars

Borghese+ 2015, 2017

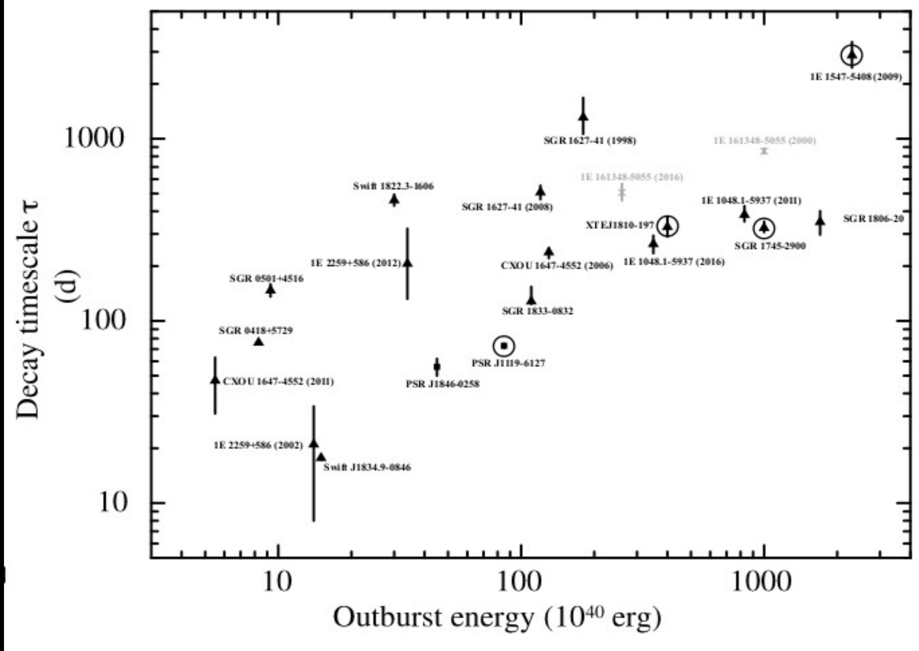
Magnetar Outburst Online Catalog



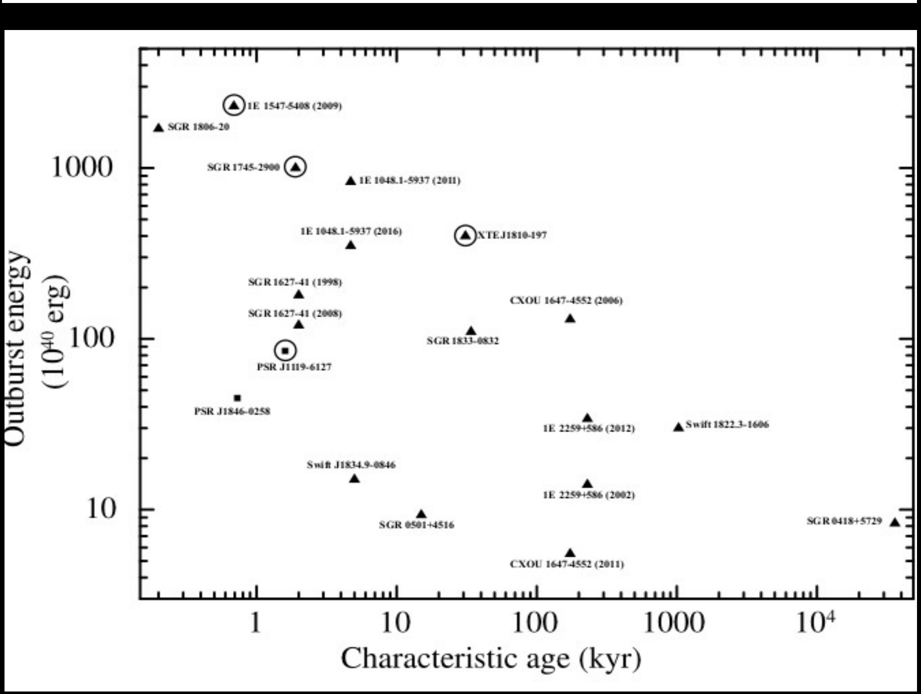
First parameter	Second parameter	Corr (c) or anticorr (a), Significance (σ) for Spearman/Kendall τ tests	PL index
Quiescent X-ray luminosity	Maximum luminosity increase	(a), 5.7 / 4.9	−0.7
Spin-down luminosity	Quiescent bolometric luminosity	–	–
Dipolar magnetic field	Quiescent bolometric luminosity	(c), 3.2 / 2.9	2.0
Dipolar magnetic field	Maximum luminosity	(c), 2.5 / 2.4	0.5
Dipolar magnetic field	Decay time-scale	–	–
Dipolar magnetic field	Outburst energy	(c), 3.7 / 3.3	1.0
Characteristic age	Outburst energy	(a), 3.3 / 3.0	−0.4
Maximum luminosity	Outburst energy	(c), 4.0 / 3.7	1.4
Quiescent bolometric luminosity	Outburst energy	–	–
Maximum luminosity	Decay time-scale	–	–
Outburst energy	Decay time-scale	(c), 3.9 / 3.6	0.5
Outburst energy	Maximum luminosity increase	–	–
Decay time-scale	Maximum luminosity increase	–	–

Coti Zelati+ 2018

Magnetar Outburst Online Catalog



Longer the outburst, the more energetic



Young magnetars tend to experience more energetic outbursts than older ones

Coti Zelati+ 2018